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WASTE DISPERSION CHARACTERISTICS AND EFFECTS IN AN OCEANIC ENVIRONMENT

by

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Operation of a waste disposal system for oceanic dispersion offered an opportunity to develop a mathematical model of dispersion behind a moving barge. The model takes into account the vertical temperature-density structure of the ocean, and the density and settling characteristics of the wastes. It was verified with several sets of field data obtained behind the barge.

Studies on marine life of the disposal area showed no changes definitely attributable to the disposal operation.

Cost data on the barging operation are given.

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report is a product of the above efforts. It attempts to evaluate the effects of a complex industrial waste on the local marine environment and the operating costs, thus contributing to the knowledge base needed to establish the utility of ocean disposal as an alternate technique. The accumulated data also serves as a basis for a first-level mathematical model in assessing other ocean disposal situations.

For further information on this subject, contact the Metals and Inorganic Chemicals Branch, Industrial Pollution Control Division.

David G. Stephan
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ABSTRACT

Operation of a waste disposal system for oceanic dispersion offered an opportunity to develop a mathematical model of dispersion behind a moving barge. The model takes into account the vertical temperature-density structure of the ocean, and the density and settling characteristics of the wastes. It was verified with several sets of field data obtained behind the barge. Results show, and the model reproduces, that the wastes do not reach the ocean bottom when a thermocline is present. They are distributed from top to bottom (140 ft) when the ocean is isothermal.

Studies on marine life of the disposal area showed no changes definitely attributable to the disposal operation. Additional information is needed to establish whether a seasonal fluctuation of dead sand dollars, *E. parma*, a benthic organism, is a natural phenomenon or can be attributed to wastes reaching the bottom.

Cost data on the barging operation are given.

This report was submitted in fulfillment of Project Number 12020 EAW, under the partial sponsorship of the Industrial Pollution Control Section, ORM of the Environmental Protection Agency. Work was completed June, 1974.

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In addition, the Oceanographic Program of Duke University Marine Laboratory assisted by making available the R/V Eastward on cruise E-18A-70 during which bottom photographs were taken by University of Delaware personnel. The Oceanographic Program is supported by the National Science Foundation.

SECTION I

CONCLUSIONS

DISPERSION ASPECTS

1. Initial mixing behind the barge was rapid. Although the wastes were acid, residual acid after initial mixing (10-30 minutes) was completely neutralized by the ocean waters in 1 to 4 hours after discharge.
2. There were no long-term changes in water quality in the area during the study, i.e., wastes did not accumulate in the water column.
3. When the ocean stratified during the warm months (May through October, with warm over cold water), the dispersing wastes were confined to the upper warm water layers and did not penetrate to the bottom under normal barging procedures. In the other months, when the ocean was not stratified, wastes mixed throughout the water column to the bottom.
4. Iron salts in the waste served as a tracer and the maximum range of measurable wastes indicated was no more than about 10 nautical miles from the discharged point.
5. The ocean currents were southwesterly at the bottom. In summer, the stratified surface waters moved north or northwesterly.
6. A mathematical model, simulating and predicting waste dispersion was verified by the field data. It

simulates lateral and vertical waste movement and reproduces the effect of wastes reaching the bottom only under nonstratified conditions. It should be applicable to other waste barging situations.

BIOLOGICAL ASPECTS

7. During the period of the monitoring program, no substantial changes were observed in the species composition or the abundance of the biota in the study area which could definitely be attributed to the waste disposal operation.

8. Species composition of the planktonic community was similar throughout the area at any one time. There were, of course, seasonal cycles of marine life with highest productivity in spring and fall, a natural phenomenon.

9. Species composition of macrobenthic organisms was also similar throughout the area at any one time. Most abundant species were the sand dollar, a small sand shrimp, a sea squirt and protozoa (foraminifera).

10. Sand dollar mortality was higher during winter than summer. Not established as whether this is a natural phenomenon associated with their spawning in the fall, or to waste penetration to the bottom in winter. Preliminary (emphasize preliminary) acute toxicity tests showed no mortality at waste concentrations found and predicted at the bottom from the dispersion studies. The safety factor appears to be at least 20.

11. Commercial surf clams were not found in the disposal area. Accumulations of surf clam shells were found throughout the area, even before disposal began, presumably transported in from areas to the north.

12. Bottom sediments were fine to coarse sand and contained iron concentrations similar to those found in the New York Bight area.

BARGING COSTS

13. Total barging costs (1971) including depreciation and operation of shore storage facilities were about $0.76 per ton, or about $3.79 per 1,000 gallons of waste.

SECTION II

RECOMMENDATIONS

1. If possible, verify the mathematical dispersion model for another waste dispersal situation.
2. Investigate how waste dispersion can be improved to minimize the waste concentrations that reach the ocean bottom during nonstratified conditions.
3. Do long-term field monitoring of the marine life in waste disposal areas.
4. Perform laboratory tests on the sublethal effects of the wastes on feeding, metabolism, reproduction and behavior of selected marine organisms to permit development of guidelines for maximum permissible waste loads in the area.

SECTION III

INTRODUCTION

The concept of total recycle of waste materials of an industrial society has a magical appeal to those concerned with environmental control. This concept, however, does not adequately recognize that modern industrial societies draw upon reservoirs of nonrenewable resources which natural forces have deposited in the oceans, in the atmosphere, or in the ground over the geological ages. Since, with the exception of some radiological phenomena, matter cannot be created nor destroyed, these resources must eventually be returned to the oceans, to the air, or the earth whence they came. The distribution of that deposition will be changed by society, but the ultimate deposition will not.

Perhaps an example will be helpful. Man extracts petroleum from the earth, and uses most as a source of energy. Air pollution control regulations require that the sulfur in petroleum be removed prior to burning certain petroleum fractions. Once the sulfur is removed, something must be done with it. Most of the sulfur recovered and recycled becomes the sulfate salt of metals such as sodium or calcium. Some is returned to the earth as insoluble or poorly soluble sulfates (e.g., calcium). Much, however, ultimately reaches, or will reach, the oceans in soluble form, either directly or indirectly. Thus, regardless of the number of recycles, once the sulfur is removed from the ground in petroleum, it eventually reaches the ground or the oceans.

The oceans, wisely used, can serve as a receiver of excess amounts of used resources for which no economical means of recycle have been developed. By economical means is meant all techniques useful to a society in recycling resources while still maintaining its economic health vis-a-vis competing societies. Industrial societies need to regulate the use of the assimilative capacity of the oceans to most wisely avail themselves of this resource. The purpose of this study was to evaluate a specific disposal operation to assess how wastes disperse in an ocean environment and the effects, if any, on other ocean resources, e.g., marine life. The report examines the effects on a localized portion of the marine environment well off the coast of Delaware due to the barge discharge of an industrial wastes from the Edge Moor, Delaware, plant of the E. I. du Pont de Nemours and Company.

The following were the specific objectives of this project:

1. Determine the rate of mixing of wastes from a moving barge;
2. Determine any accumulation of the wastes in the water column;
3. Develop and verify a time variable mathematical model to describe the lateral and vertical movements of the wastes;
4. Assess the sediments and marine life in the water and on the bottom to establish whether any detectable changes were occurring.

The wastes barged come from the manufacture of titanium dioxide pigment. The specially designed barge, described by Fader[1], is 270 feet long, 60 feet wide, and 18 feet deep, and has four rubber-lined cargo tanks with a total capacity of about one million gallons (5,000 tons). Radio-controlled signals from a towing tug release the wastes from the unmanned barge in a designated disposal area. An elaborate control system assures that wastes cannot be released except upon specific command.

Wastes flow from the barge by gravity in a disposal area recommended by the U.S. Interior Department's Bureau of Commercial Fisheries (now the National Marine Fisheries

Service, Department of Commerce). The waste disposal area encompasses a rectangle 5 by about 8 nautical miles centered approximately 38 nautical miles southeast of Cape Henlopen, Delaware (shaded area, Figure 1). The area is bounded by 38°30' and 38°35' north latitude, and by 74°15' and 74°25' west longitude. The sea throughout the area is between 125 and 150 feet (38 and 45 meters) deep. The barge is towed to sea approximately 2 to 3 times a week. Discharge time is usually about 60 minutes at a speed of 6 knots if weather and other conditions permit. The waste at the time of this study was 17% to 23% acid (expressed as H_2SO_4) and 4 to 10 percent ferrous sulfate. Similar wastes have been dispersed at sea for 25 years in the New York Bight[2]. Available data[3-10] indicate that this operation has had no significant effects on ocean resources of the area.

Ocean disposal of the Edge Moor wastes began in September 1968, in an area centered about 10 nautical miles southeast of the above designated site on a temporary basis. This alternate area was used until July 1969, pending completion of predisposal surveys in the primary area. These were done in May and June 1969, and barging began in the present area in July 1969.

Hydroscience, Inc., supervised cruises to collect data to assess the dispersion processes behind the moving barge, and to monitor chemical and physical changes in the water quality of the disposal area. The University of Delaware's College of Marine Studies obtained information on the marine life of the area and assessed changes, if any. The College did its field work either on cruises with Hydroscience, Inc., or independently. Table 1 shows the coordinates of sampling stations and Table 2 lists the cruise record.

The details of this report are presented in three sections:

Section IV, "Dispersion of Wastes Behind a Moving Barge", and Section VIII, Appendices A-1 through A-3 cover dispersion studies, the hydrographic and chemical data developed concurrently with them and the mathematical model developed to simulate dispersion.

Section V, "Effects on Marine Biota", and Section VIII Appendices B-1 through B-3, evaluate the marine life studies in and near the disposal area. Where possible, the relationship to the dispersion process is indicated. Information on sediments is included here.

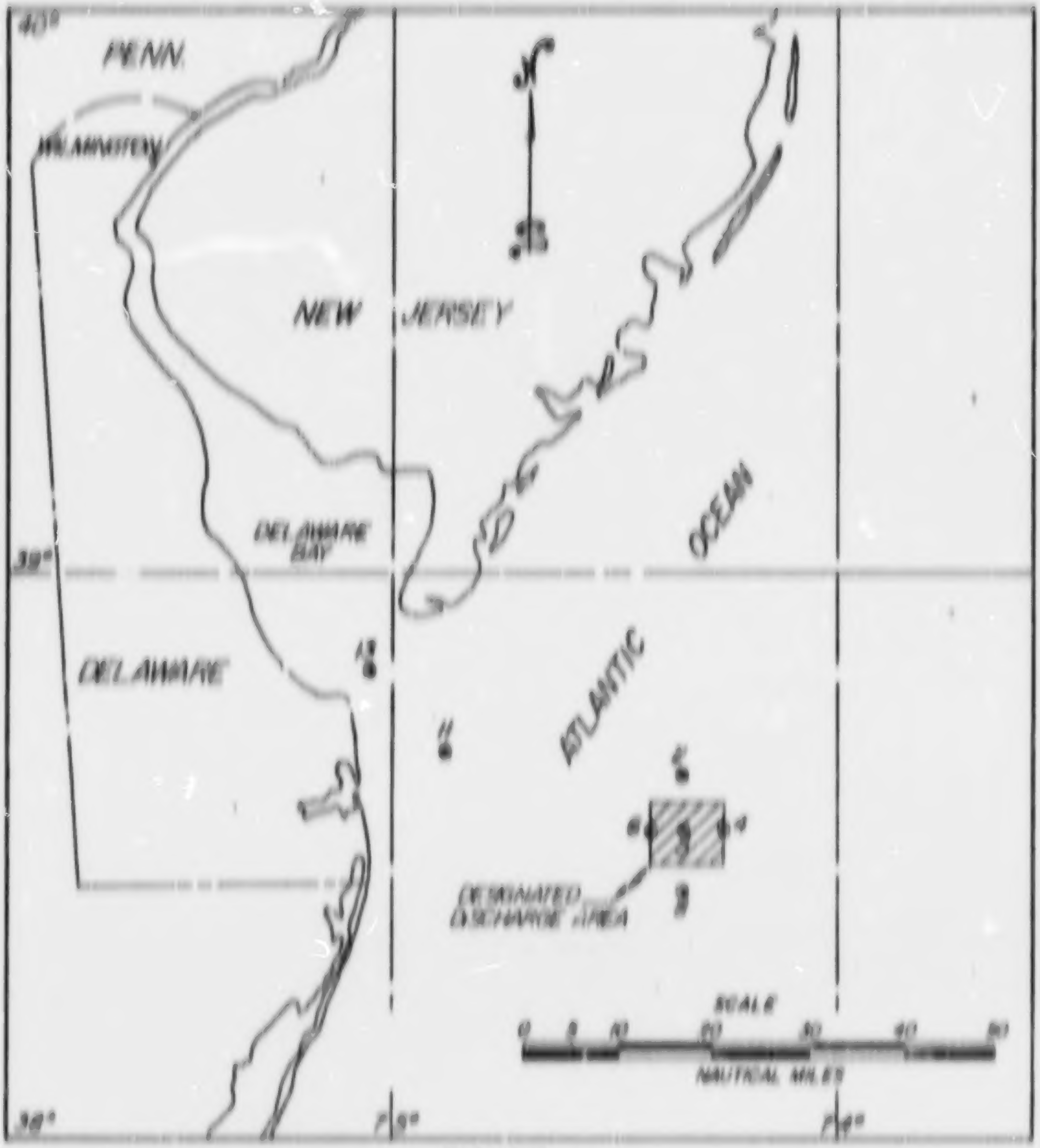

40°
PENN.
WILMINGTON
NEW JERSEY
DELAWARE BAY
DELAWARE
ATLANTIC OCEAN
39°
DESIGNATED DISCHARGE AREA
SCALE
0 5 10 20 30 40 50
NAUTICAL MILES
38°
75°
74°

FIGURE 1
LOCATION MAP OF BARGE DISCHARGE AREA AND SAMPLING STATIONS

TABLE 1

COORDINATES OF SAMPLING STATIONS

Station Designation	Coordinates	
2	74°20' W	38°38-1/2' N
4*	74°15' W	38°32-1/2' N
5*	74°20' W	38°32-1/2' N
6*	74°25' W	38°32-1/2' N
8	74°20' W	38°26-1/2' N
11†	74°53' W	38°41-1/2' N
13†	(buoy #4 entrance to Bay)	

* In designated barge discharge area.

† Top samples only.

TABLE 2

CRUISE RECORD

	Background Surveys	Cruise Designation
	15 May 1969	K-01-69
	28 May 1969	P-01-69
	29 June 1969	A-01-69
	Monitor Surveys	
#1	11 October 1969	K-02-69
#2	14-16 May 1970	K-03-70
	25 May 1970	S-02-70
	1 June 1970	S-03-70
#3	8 July 1970	S-06-70
#3A	18 July 1970 (bottom photos only)	E-18A-70
#4	4-6 August 1970	K-04-70
	5 August	S-07-70
#5	8 October 1970	S-09-70
#6	17 November 1970	S-10-70
#7	19 January 1971	S-01-71
#8	2-10 March 1971	K-05-71
#9	27 May 1971	S-02-71
	1 June 1971	S-03-71

Vessel Code:

K = Kyma
P = Pathfinder
A = Albatross IV
S = Skimmer
E = Eastward

Section VI is a summary of barging costs for the Edge Moor Plant based on 1971 data, through August.

SECTION IV

DISPERSION OF WASTES BEHIND A MOVING BARGE

This portion of the report and its associated Appendix VIII-A are based on studies conducted by Hydroscience, Inc., in three phases. The first was an evaluation of data obtained during the surveillance program.

The second incorporated development of a time variable mathematical model to simulate the dispersion and settling of the waste in the marine environment utilizing total iron as a tracer for the waste. The analytical method was first to verify data obtained in the laboratory, under more controlled conditions, to determine the applicability of the proposed theory. Verification of the cruise data was subsequently done with a consistent set of dispersion and settling parameters to approximate average conditions, along with unique input and density fields for each survey. On this basis, the model is considered to form a useful means for first estimates of the effects of the waste discharge on the vertical and horizontal distribution of the waste.

The third phase involved applying the model under the "critical" conditions, which appears to occur during periods of homogeneous density regime, to simulate the effects of varying barge discharge procedures.

SECTION IV-A

SURVEILLANCE PROGRAM

PURPOSE

During the period May, 1969, through March, 1971, five cruises were conducted aboard the New York University Research Vessel, KYMA:

Cruise K-01-69:	May, 1969 (Baseline survey)
Cruise K-02-69:	October, 1969 (Fall)
Cruise K-03-70:	May, 1970 (Spring)
Cruise K-04-70:	August, 1970 (Summer)
Cruise K-05-71:	March, 1971 (Winter)

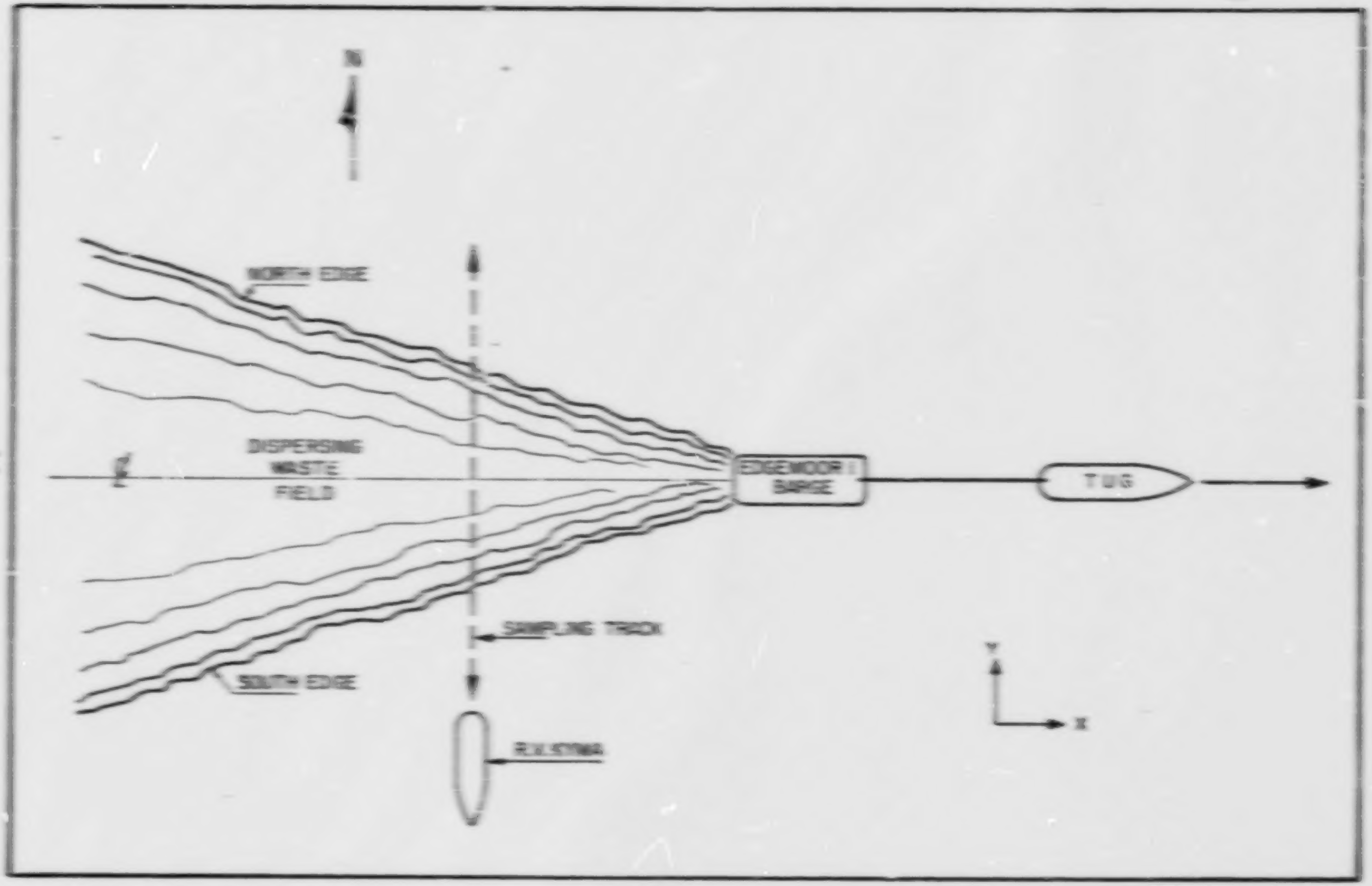
Cruise K-01-69 occurred prior to discharge of waste in the designated disposal area. These data provide baseline information on the physical, chemical, and biological aspects of the area.

After discharge began in the primary disposal area in July, 1969, four additional "full" surveys were conducted during different seasons of the year. These surveys were concerned with the dispersion of the waste and effects on the chemistry and biology of the area. Each survey was separated into a "background" study and "dispersion" studies. The former concentrated on background levels of such water column constituents as chloride, pH, dissolved oxygen, iron, phosphate, alkalinity, and nitrogen. Biological samplings conducted by the University of Delaware, College of Marine Studies, are reported in Part V. The "dispersion" studies dealt with tracing the waste plume as soon after discharge as possible. This involved extensive measurements of iron (used as the tracer element in the mathematical model) alkalinity, and pH. In addition, temperature and salinity profiles, light penetration, and ocean currents were measured to assess water masses and movement during different seasons.

GENERAL PROCEDURE

The "background" studies involved complete sampling at five stations. Three were in the designated disposal area, while the remaining two were designated as control stations, located 3.5 nautical miles north of the northern limit (Station 2) and 3.5 nautical miles south of the southern limit (Station 8) of the disposal area. Samples were usually taken at three depths: surface, 50, and 100 feet. Two additional stations, occasionally sampled at the surface only lay between the disposal area and the mouth of the Delaware Bay. (Table 1 and Figure 1).

For the "dispersion" studies the barge, the Edge Moor I, would usually begin being discharged from the western edge of the disposal area proceeding in an easterly direction. The KYMA would cross the surface plume of dispersing wastes perpendicularly to set a reference buoy in the centerline and sampling commenced. There was usually a ten to twenty minute delay for navigational safety prior to the first sample. The KYMA would continue to cross, perpendicularly, the same general patch of waste with samples taken at the north edge, centerline, and south edge of the surface plume, with occasional sampling in clear water, both south and north of the plume. Three to five samples were taken at each station ranging from the surface to about 100 feet. Figure 2 shows, schematically the procedure used. The location in the waste plume was based on visual approximation of the surface plume. Decca coordinates were taken at all stations except during Cruise K-05-71 when only Loran coordinates were available. The sampling procedure provided for measurements at the edges of the visual surface waste plume as well as in the clear surface water to assure that subsurface waste plumes resulting from directional current shear would not be missed.



N
NORTH EDGE
DISPERSING
WASTE
FIELD
℄
SOUTH EDGE
SAMPLING TRACK
R.V. SYMA
EDGEMOOR I
BARGE
TUG
Y
X

FIGURE 2

SCHEMATIC OF DISPERSION STUDY
SAMPLING PROCEDURE

Current measurements were taken during Cruise K-01-69 with an Ekman current meter and Carruthers current measuring device. Continuous mode current measuring devices were used for three of the remaining cruises. Two or three devices located in the center of the disposal area (Station 5) at depths of 25 to 140 feet gave continuous recordings of current speed and direction for a period of about 30 hours during Cruise K-02-69 and 55 hours each during Cruises K-03-70 and K-04-70. Because of possible difficulties expected in retrieving the continuous current devices during winter, they were not used during Cruise K-05-71. A review of general current patterns in the area determined placement of the current meters at Station 5. Although current meters at additional stations would have been desirable, budgets limited the direct current observation program. Station 5 is, however, representative of the general drift in the area[11].

A standard photometer measured light penetration and extinction coefficients were calculated from:

$$\frac{I}{I_o} = \exp\,(-k_e\ Z) \qquad (1)$$

where I/I_o is the ratio of light received at depth Z to that at the surface, and k_e, $(\text{ft})^{-1}$, is the overall extinction coefficient.

A bathythermograph (BT) measured temperature as a function of depth. Additionally, surface temperatures were taken with a standard thermometer. Salinity measured through the water column permitted, based on tables obtained from the United States Navy Hydrographic Offices[12], calculation of water column density. Computed σ_t values are given by:

$$\sigma_t = 1000\ (\rho_o - 1{,}000) \qquad (2)$$

where ρ_0 is the density of the seawater.

An AutoAnalyser® was used to measure iron concentrations. The standard procedure was modified for the determination in saline waters and to account for the trace amounts of iron in the sulfuric acid preservative used in the field. The sensitivity of the AutoAnalyser® testing procedure is about 10 µgFe/l (ppb). Because contamination can occur during sampling[13] and in the handling and transporting of the samples, a total iron concentration of about 100 µg/l was selected as a "background level" from which departures due to waste discharges could be measured. This corresponds to a waste dilution of about five orders of magnitude.

Table 3 summarizes the basic work completed during the five cruises. Of the seven dispersion studies, five were conducted at the normal operating barge speed of about six knots, while the remaining two were at a barge speed of about three knots. Table 4 summarizes the waste characteristics as measured by E. I. du Pont de Nemours and Company.

SUMMARY OF CRUISES

Specific details of each cruise are in Appendix A-1. A general discussion of the surveillance program follows:

Current Regime

Continuous current measurements in the center of the disposal area (Station 5) during Cruises K-02-69, K-03-70, and K-04-70 show a rotary tide with substantial directional shear over the depth of the water column. This shear was especially prevalent during Cruise K-04-70 (August, 1970) as shown in Figure 3 which presents Eulerian vector plots of water mass movement at various depths.

Direct on-shore currents were relatively minimal in both magnitude and frequency. Bottom water generally moved southwesterly from the disposal area as shown in both Figure 3 and Figure 4 (Cruise K-03-70, May 1969). Surface currents were more variable. During Cruise K-03-70, a general southwest surface drift was noted, while during Cruise K-04-70, a general northwest surface drift was noted, a

TABLE 1

SUMMARY OF CRUISES

Cruise	Date	Background Study	Dispersion Study	Current Measurment
K-01-69	May 14,15, 1969	1	-	Discrete
K-02-69	Oct 10,11, 1969	1[††]	2*[†]	Continuous
K-03-70	May 14-16, 1970	1	2[†]	Continuous
K-04-70	Aug 4-6, 1970	1	2	Continuous
K-05-71	Mar 2,10, 1971	1[†††]	1	None

* Both dispersion studies conducted on one day.
[†] Conducted at two barge spuds.
[††] Only partially completed due to tropical storm.
[†††] Background study delayed due to poor weather.

TABLE 4

EDGEMOOR I BARGE LOADS

FOR SPECIFIC PERIODS

Cruise	Date	Disposal Time* Start	Disposal Time* Stop	Approximate Barge Speed (knots)	Raw Waste Characteristics Fe (mg/l)	Raw Waste Characteristics H_2SO_4 (%)	Raw Waste Characteristics Acidity (mg/l as $CaCO_3$)	Raw Waste Characteristics Sp. Gr.
E-02-69								
Line A	10/20/69**	0910	0930	6	27,900	19.03	229,200	1.1805
Line B		1225	1310	3				
E-03-70								
Line A	05/14/70	0912	0957	6	28,200	19.80	240,900	1.1924
Line B	05/16/70	0922	1005	3	24,700	17.46	207,800	1.1665
E-04-70								
Line A	08/04/70	0910	1015	6	45,600	17.03	208,000	1.1978
Line B	08/06/70	0900	1010	6	44,600	16.65	202,600	1.1925
E-05-71	03/02/71	0850	0935	6	24,600	17.22	205,000	1.1667

* Eastern daylight saving time, except 3/2/70, which is eastern standard time.
** Load was discharged in two portions for FWQA study of dispersion.

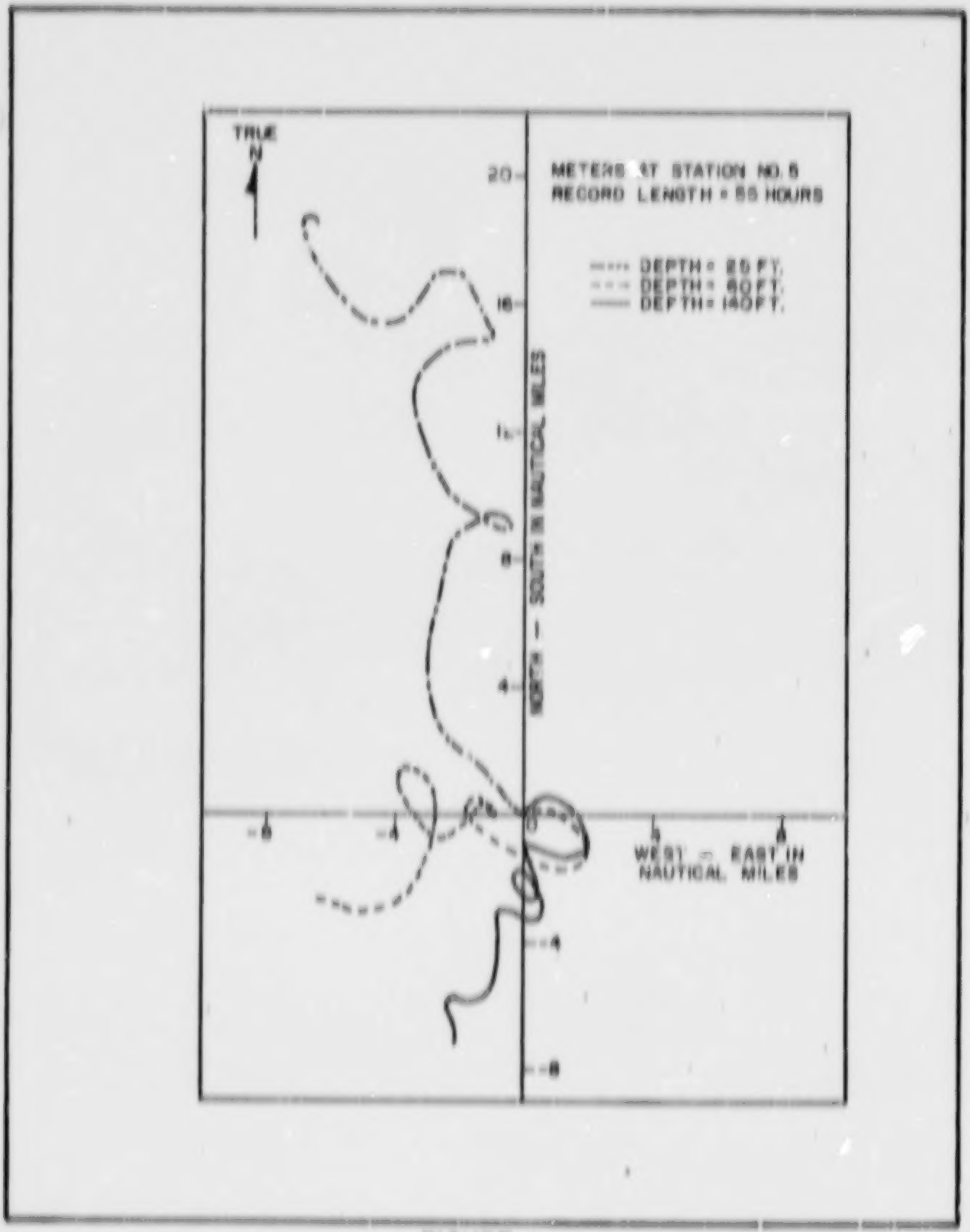


FIGURE 3
CONTINUOUS CURRENT METER RESULTS
CRUISE K-04-70 AUGUST 4-6, 1970

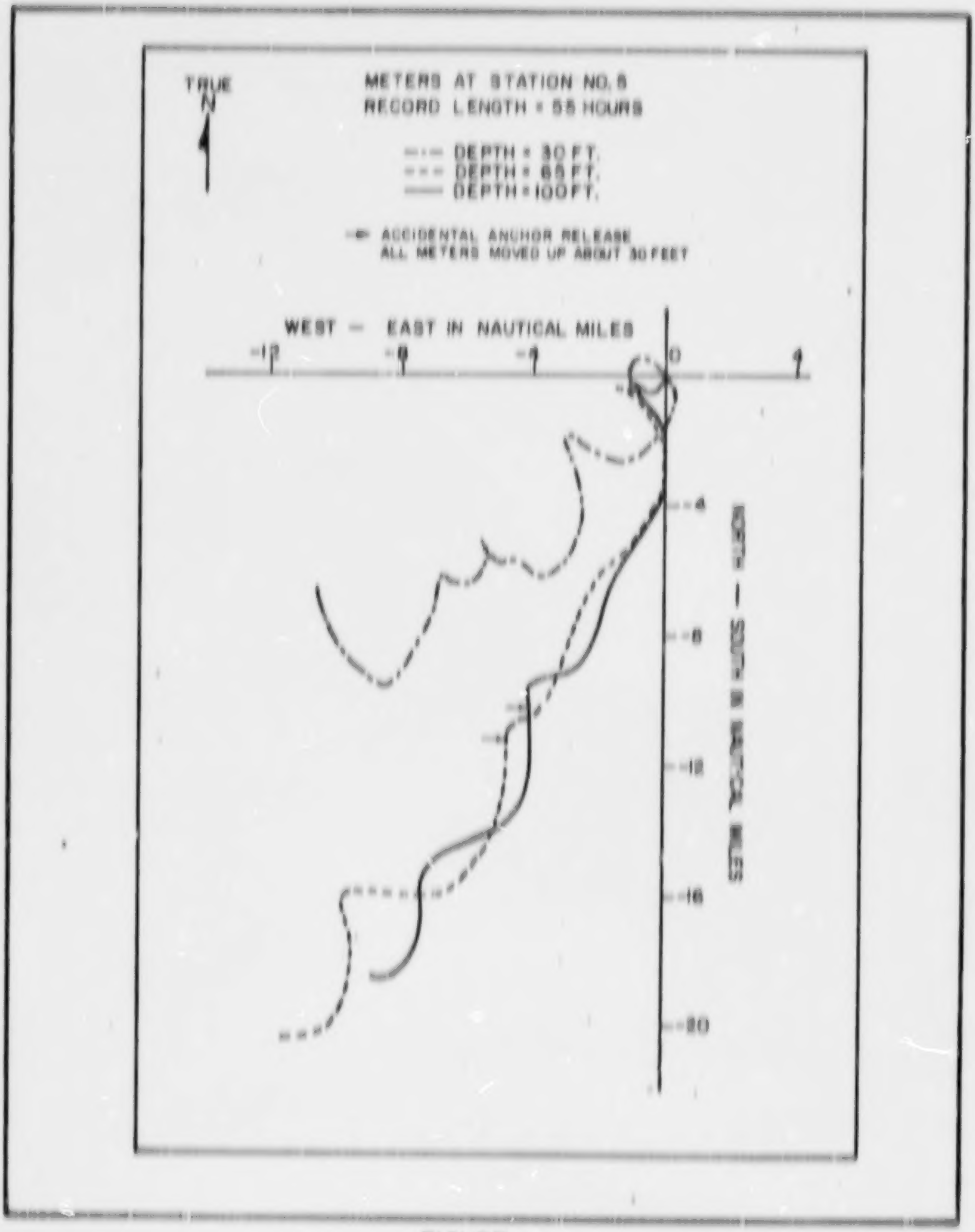


FIGURE 4
CONTINUOUS CURRENT METER RESULTS
CRUISE K-03-70 MAY 14-16, 1970

reversal of surface currents during the late spring and summer periods. Current speeds averages from about 0.4 to 0.8 knot for the three cruises measured. A few maximum sustained velocities of about one knot were recorded. Figures 3 and 4 show the maximum net spatial drift observed was about 20 nautical miles for the lengths of record involved. This corresponds to a maximum net drift velocity of about 0.36 knot (8.7 nautical miles/day).

Residual surface and bottom currents were determined by the University of Delaware from returns of balasted drift bottles and sea bed drifters (see Section V-C). The results generally concur with the continuous current data: A general south-westerly movement of bottom water from the disposal site, with a reversal of surface currents during the late spring and summer periods. The maximum travel time recorded from the disposal area (Station 6) was 7.4 nautical miles per day to the southwest.

Water Quality Data

In general, the data collected during the five background studies indicate no substantial changes in the chemistry of the water column of the study area that could be attributed to the barging operations. Dissolved oxygen values were at or near saturation at most stations. Alkalinity at the five primary stations varied from about 114 mg/l to 125 mg/l as $CaCO_3$. Values of pH averaged about 8.2, with a range of 7.8 to 8.8. Variation in nitrogen and phosphate levels was attributed to expected seasonal changes. Light extinction coefficients averaged about 0.03 $(ft)^{-1}$ for most studies, and are indicative of sustained clarity with no long-term effect on light penetration.

No substantial trend in the total iron concentrations was detected. For Cruise K-01-69, total iron concentrations at the five primary background stations ranged from 31 to 113 µg/l, while for the remaining four cruises the total iron concentrations ranged from less than 10 to 110 µg/l. In addition, the two control stations, 2 and 8, were not significantly different from the three stations in the disposal area for any of the cruises. It is concluded that the disposal at sea (about every three days) did not contribute to any change in water quality in the area of investigation over the length of the surveillance program.

Dispersion of Wastes

The initial mixing and dilution of the waste after discharge is quite rapid. The highest measured total iron concentration was about 24 mg/l, recorded during Cruise K-03-70 - Line B (conducted at a barge speed of about 3 knots), 15 minutes after discharge. When compared to the initial iron concentration of about 25,000 mg/l on that date (Table 4) this constitutes a dilution by three orders of magnitude in a period of about 15 minutes. The iron concentration of the waste was diluted by three to four orders of magnitude during the first 30 minutes after discharge during all of the dispersion studies. The maximum initial dilution occurring during Cruise K-05-71, which was conducted under conditions of a homogeneous density regime.

The alkalinity and pH measurements indicate an even more rapid dilution of the waste after discharge. The first few pH values measured after discharge for the various dispersion studies ranged from about 6 to 7, except for the Cruise K-03-70 Line B dispersion study, where a unique pH value of 3.4 was recorded. Since the pH of the raw waste is less than 0.1, a pH of 6 constitutes a change in the hydrogen ion concentration by six orders of magnitude. This occurred in the first 10 to 20 minutes after discharge for all of the dispersion studies.

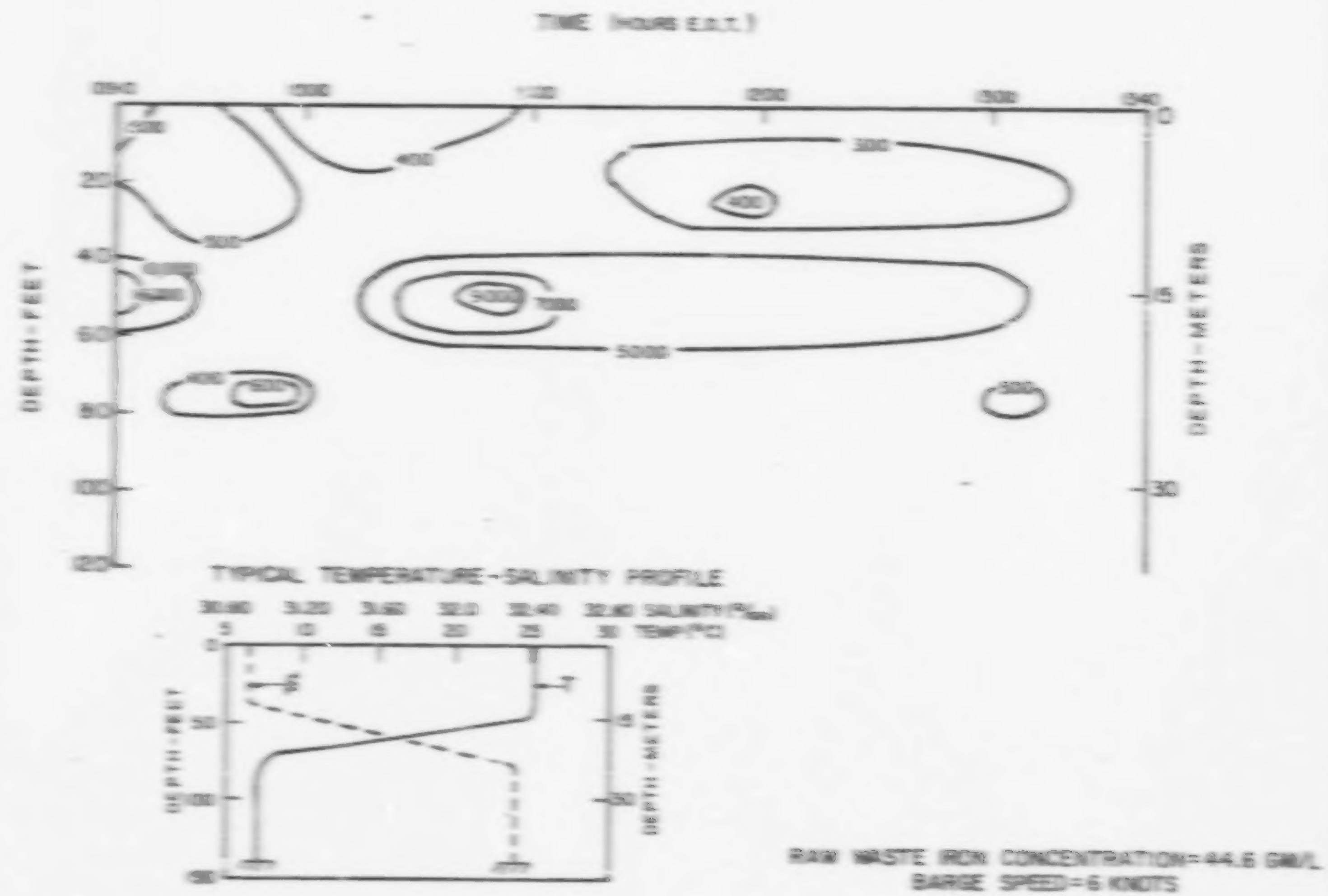
The range of the lowest alkalinities encountered for the various dispersion studies was about 45 to 110 mg/l as $CaCO_3$. Since the waste's acidity represents "negative" alkalinity, these values correspond to a dilution of raw waste by about three to four orders of magnitude during the first 10 to 20 minutes after discharge. Both alkalinity and pH generally returned to background levels within approximately one to four hours after discharge for six of the seven dispersion studies. Since pH and alkalinity are functions of chemical equilibria as well as the physical dispersion and settling phenomena, it may be postulated that the chemical formation of a ferric iron floc has also been generally completed during this period. As a result, any persistant iron concentrations measured at times significantly after this initial mixing period are probably suspended iron floc in an otherwise neutralized environment.

Studies done during different seasons of the year showed that homogeneous and nonhomogeneous density regimes of the ocean had a substantial effect on dispersion. During the summer the wastes did not penetrate below the vicinity of the thermocline. Figure 5 shows the total iron concentration along the assumed centerline of the waste plume as a function of time and depth, as well as a typical temperature-salinity profile. Even during fall and spring, a relatively mild thermocline prevented penetration of the waste to depths below the vicinity of the thermocline under normal barge discharge procedures (Figure 6). However, indication of the settling of the waste into deeper water was noted during the winter period when an isothermal regime exists as demonstrated in Figure 7. Therefore, the time of year is important with respect to the possible accumulations of the settleable constituents of the waste on the ocean floor. Since the relatively nonmotile benthic community can act to integrate waste effects, winter has been assumed to be the "critical" period.

The effect of the barge speed was observed during Cruise K-03-70. Comparison of Line A data (at 6-knots barge speed) with that of Line B (3-knots) indicates the waste remains closer to the surface at faster barge speed. Some penetration of waste below the thermocline occurred during the Line B study. The larger downward velocity imparted to the waste because of higher initial plume concentrations (density) may be the cause.

During the Cruise K-04-70 - Line B study consistently higher iron concentrations remained in the vicinity of the thermocline for a longer period after discharge (Figure 5). Alkalinity and pH measurements also indicate a substantial presence of the waste even after five hours. It appears that the decreased mixing volume available as a result of the presence of a strong thermocline resulted in lateral dispersion being the predominant phenomena responsible for returning the iron concentrations to background levels. Extrapolation indicates that a period in excess of twenty hours would be necessary for the iron concentration to return to background levels in the water column. However, since the waste plume is constantly spreading, an accompanying increase in the dispersion and dilution of the waste is probably due to the encompassing of larger eddies, as well as the overall influence of the current directional shear and circulation patterns.

During dispersion studies conducted under mild or no thermocline conditions, a more rapid return to background levels over the depth of the water column sampled was generally

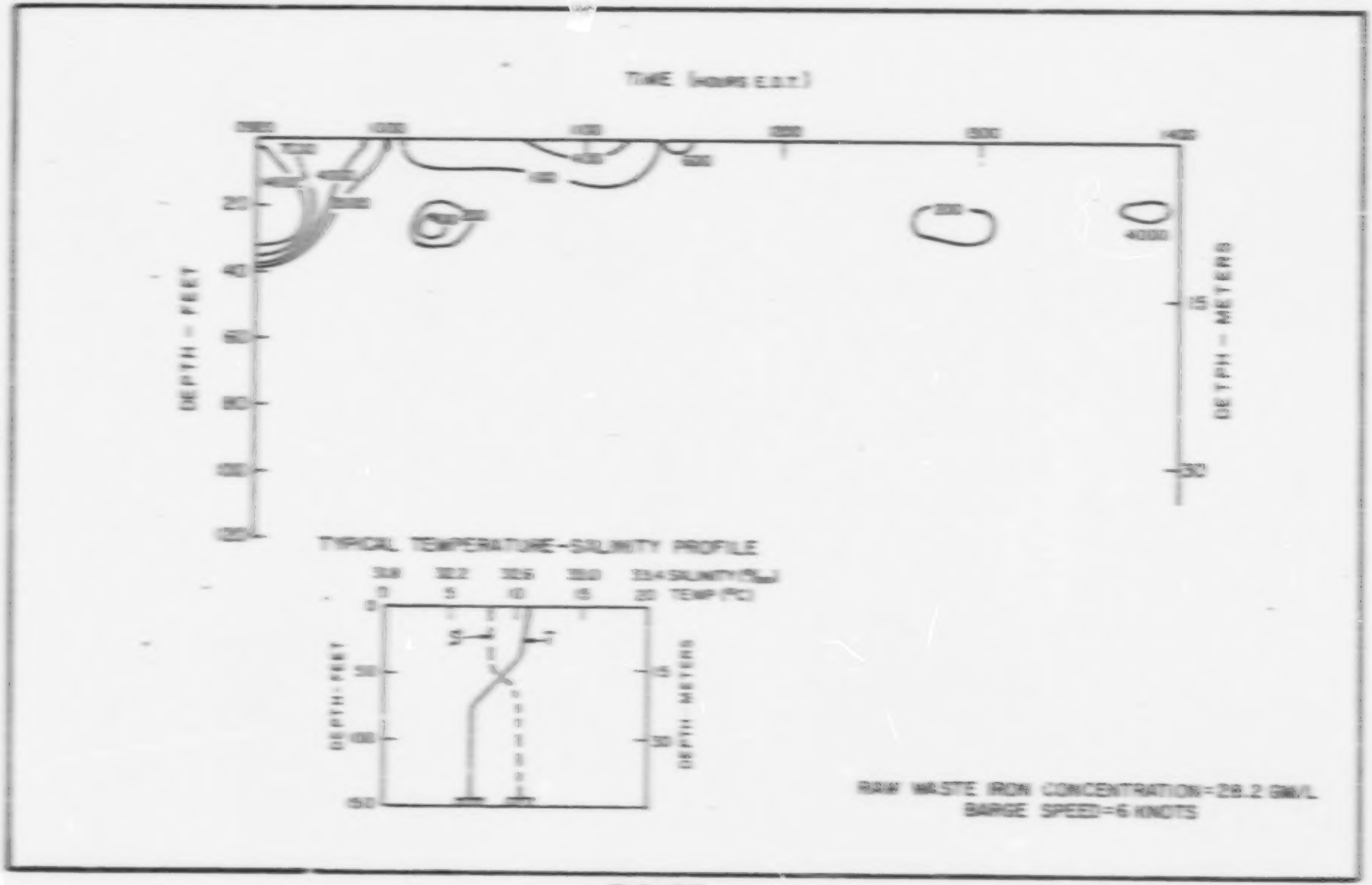


RAW WASTE IRON CONCENTRATION=44.6 GM/L
BARGE SPEED=6 KNOTS

FIGURE 5

TOTAL IRON (μG/L) ALONG CENTERLINE

CRUISE K-04-70 LINE B AUGUST 6, 1970

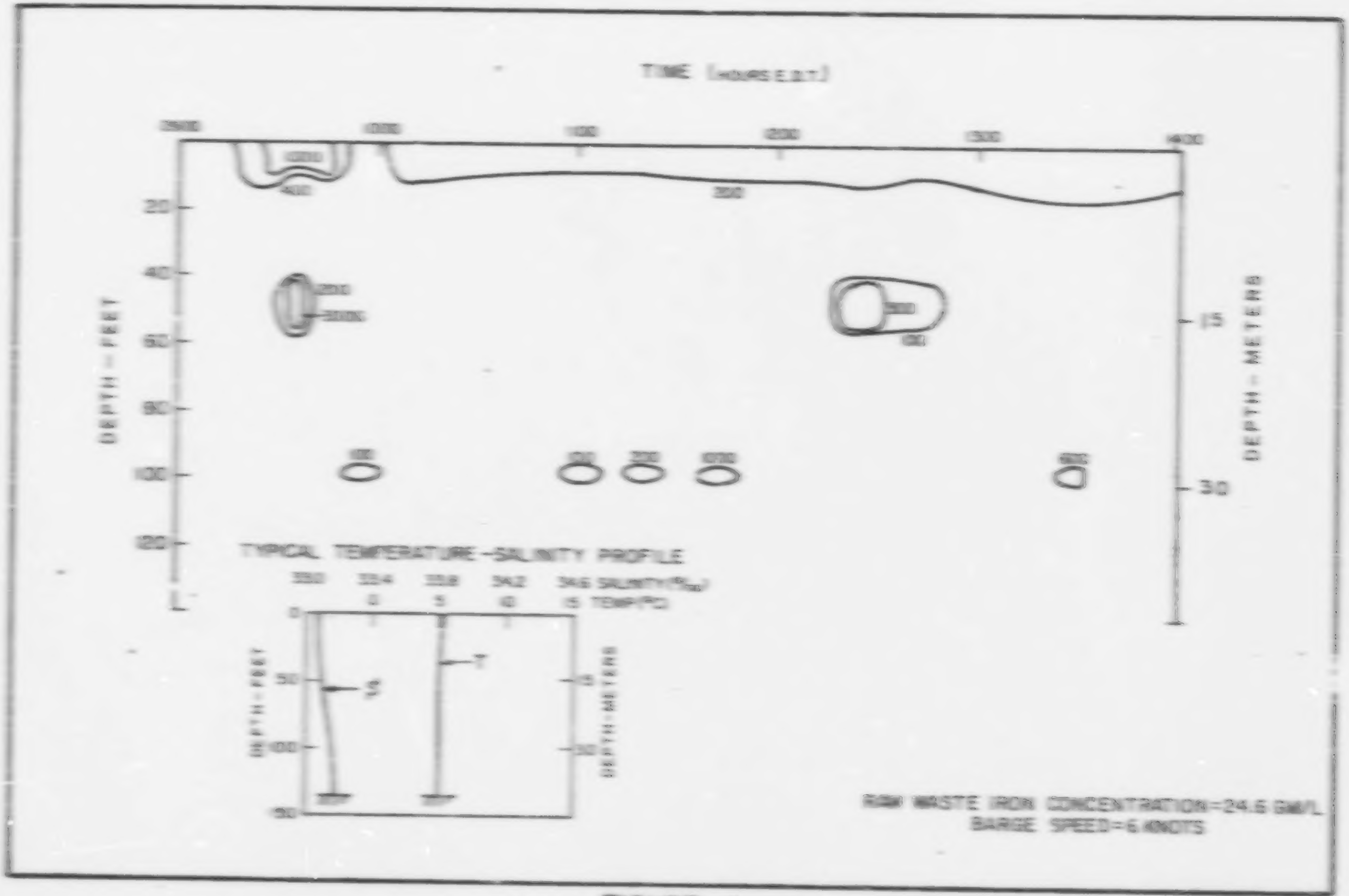


RAW WASTE IRON CONCENTRATION=28.2 GM/L
BARGE SPEED=6 KNOTS

FIGURE 6

TOTAL IRON (μG/L) ALONG CENTERLINE

CRUISE K-03-70 LINE A MAY 14,1970



RAW WASTE IRON CONCENTRATION=24.6 GM/L
BARGE SPEED=6 KNOTS

FIGURE 7

TOTAL IRON (µG/L) ALONG CENTERLINE
CRUISE K-05-71 MARCH-2, 1971

noted. For example, during the Cruise K-05-71 study, observed iron concentrations were at or near background levels over the depth of the water column within five hours after discharge. The maximum time for the total iron concentrations in the water column to return to background levels was estimated at from approximately five up to twenty hours after discharge. Since the acidity of the waste is more rapidly neutralized, the persistent iron concentrations, especially for the longer periods, would most probably be solely indicative of a suspended ferric floc in an otherwise neutralized environment with respect to acidity and alkalinity.

The maximum net drift velocity recorded was approximately 8.7 nautical miles per day (*supra*). Thus, the estimated maximum spatial range of influence, defined by iron concentrations above background levels, extends about ten nautical miles from the point of discharge and would probably occur during the summer period. The general movement of the waste field would be to the southwest, except during reversals (late spring and summer), when the wastes above the thermocline moved to the northwest.

Light penetration studies were conducted in a dispersing waste plume during the Cruise K-04-70 - Line B dispersion study. Light extinction coefficients averaged about 0.1(ft)$^{-1}$ in the visual centerline of the waste plume during the first few hours after discharge. This was about three times that measured during the background studies. This means the depth of the one-percent surface light level decreases from about 150 feet under normal conditions to about 50 feet in the spreading plume's center. Unfortunately, since the 1% range of the submarine photometer and the beginning of the thermocline occurred at approximately the same depth, these results are inconclusive with respect to verifying that the accumulation of waste occurred in the vicinity of the thermocline. However, some indication of this accumulation was noted at a station south of the visual centerline of the waste plume.

Effects on light extinction persisted in the visual centerline of the waste plume, although maximum iron concentrations had decreased to approximately 200 µg/l Fe over the depth of the water column measured. This indicates that light penetration is affected even by a sparse ferric floc. Cruise K-03-70 provided further evidence of this when a light penetration decrease was noted in the vicinity of the thermocline, approximately nine hours after a dump. It appears that effects on light penetration may persist until iron concentrations have returned to background levels over the depth of the water column

SECTION IV-B

METHOD OF ANALYSIS

MATHEMATICAL MODEL OF DISPERSION AND SETTLING

Mathematical modeling can provide a basis for estimating waste distribution in the oceanic environment. The model constructed incorporates the major features of the horizontal and vertical discharge pattern. It did not incorporate all details of the hydrodynamic regime or changes in the waste properties due to chemical reactions. Incorporation of such phenomena would have excessively complicated the model. Rather, general approximation of those effects were utilized. Thus, the model provides an analytical framework which sufficiently duplicates observed data to predict, with some confidence, the dispersion and settling of the waste under alternative discharge schemes.

The model is based on fundamental physical principles. Its application was preceded by a comparison of calculated results to observed data in a stepwise rational fashion. The model was first compared to data obtained under controlled laboratory conditions to validate waste settling simulation and obtain settling constants. Order-of-magnitude dispersion coefficients were then obtained by two independent analyses. The model was then applied to all dispersion studies. The consistent set of parameters formulated resulted in the best model fit of all the data obtained under various field conditions.

The model is a two-dimensional (lateral and vertical) diffusion-advection mass balance equation (see Appendix A-3). A theory of discrete settling provides for vertical settling of the waste. The resulting equation is

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial y}(E_y \frac{\partial c}{\partial y}) + \frac{\partial}{\partial z}(E_z \frac{\partial c}{\partial z}) - W(c,\rho,\rho_0)\frac{\partial c}{\partial z} + S \quad (3)$$

where c = total iron concentration (M/L^3)

y = distance in lateral direction (L)

z = distance in vertical direction (L)

t = time (T)

$\frac{\partial}{\partial y}(E_y \frac{\partial c}{\partial y})$ = dispersion in lateral direction (M/L^3T)

$\frac{\partial}{\partial y}(E_z \frac{\partial c}{\partial z})$ = dispersion in vertical direction (M/L^3T)

E_y = lateral dispersion coefficient (L^2/T)

E_z = vertical dispersion coefficient (L^2/T)

W = vertical settling velocity of the waste mass relative to a vertical quiescent medium (L/T)

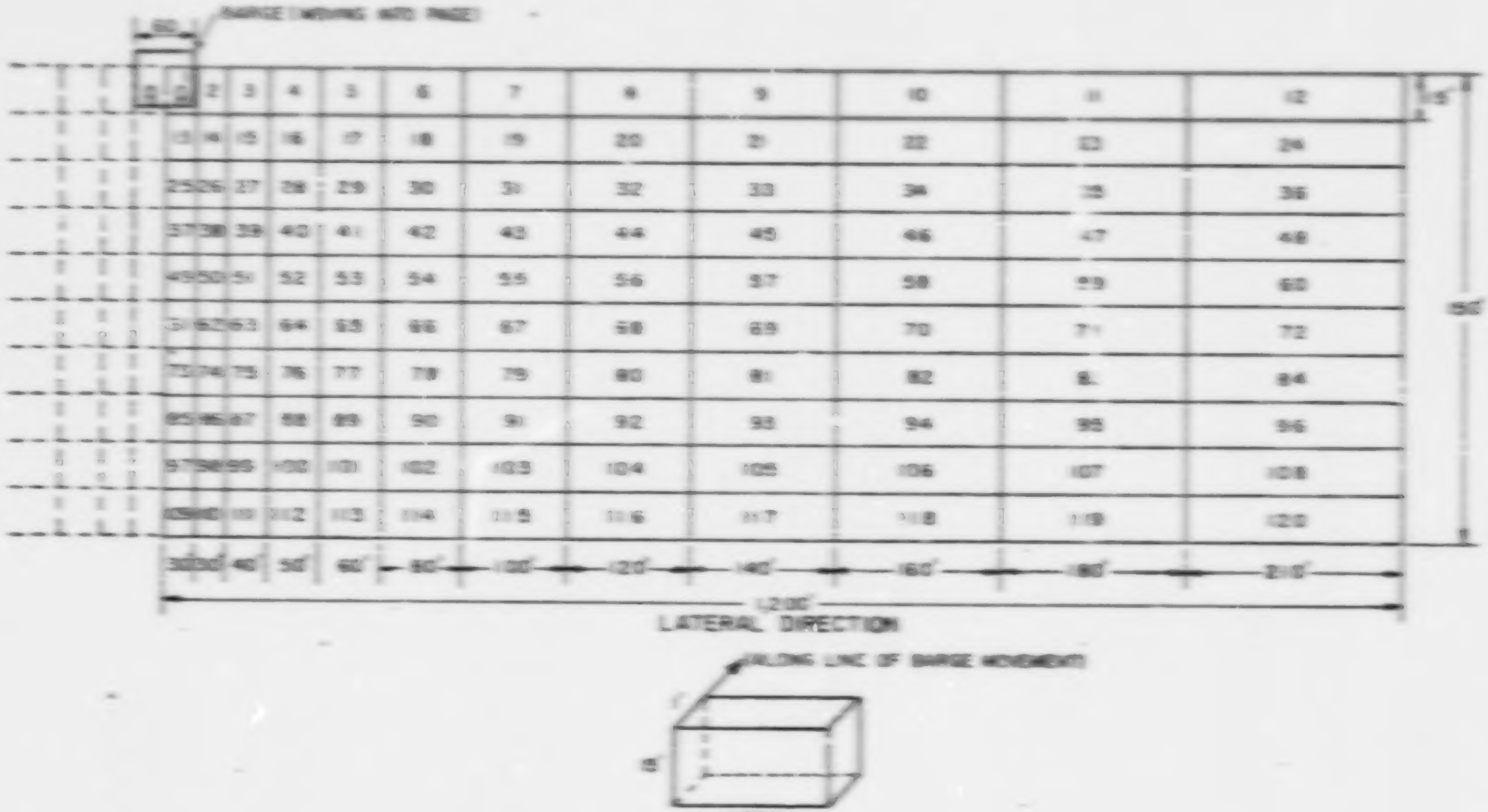
S = iron source (M/L^3T)

ρ = density of diluted waste (M/L^3)

ρ_0 = density of surrounding water (M/L^3)

and M, L, and T are the mass, length, and time units, respectively.

This nonlinear time-variable equation was solved numerically. A finite difference approach[14] was applied to a series of interconnected segments (Section VIII, Appendix A-3). Figure 8 shows 120 segments used in the model. The barge was considered moving into the page, and symmetry was assumed on both sides of the barge yielding a total model width of 2,400 feet. Since the waste is laid down as a line source, longitudinal concentration gradients would be small compared to lateral and vertical gradients. The longitudinal length was therefore taken as one foot. Instantaneous dispersion of waste in the



BARGE (MOVING INTO PAGE)
60'
1
2
3
4
5
6
7
8
9
10
11
12
15'
150'
DEPTH
30' 30' 40' 50' 60' 80' 100' 120' 140' 160' 180' 210'
1200'
LATERAL DIRECTION
(ALONG LINE OF BARGE MOVEMENT)
1'
15'
WIDTH
TYPICAL SEGMENT

FIGURE 8

MATHEMATICAL MODEL SEGMENTATION

the first segment was assumed. That segment's dimensions are 30 feet wide (60 feet considering symmetry), one foot long and 15 feet deep. The model therefore represents waste dispersion after "near-field" mixing by wake and jet turbulence.

Simulation of the immediate near-field dispersion of the waste (less than five minutes after release) would require a more sophisticated model. Field verification of such a model would be extremely difficult because of navigational and other safety reasons. In addition, little further insight into the long-term effects of the waste disposal operation would be gained. The physical dimensions of the barge and discharge apparatus determine the dimensions of the first segment. Observations of turbulence behind the barge indicated the assumption of complete mixing in the first segment would be valid. The present model can be applied to evaluate the effects of barge speed, discharge rate, and discharge apparatus (i.e. a diffuser exceeding the width of the barge).

A Langragian coordinate system was used. Therefore, the model assumed the dispersing plume followed the general drift pattern and so simulated the procedure used in the field studies. The maximum spatial translation of the dispersing waste can be approximated by applying ocean current data to the estimate of the time for the waste to be diluted to background levels.

Substantial directional shear was found in the study area. While that phenomenon was not incorporated into the model, it would tend to facilitate waste dispersion and make the simulation conservative. An attempt to include the effects of this phenomenon in the verification procedure was made by taking into account iron concentrations at the apparent edges of the waste plume when they substantially exceeded those found along the visual centerline of the plume. Figures 11 and 12, c and d, to be discussed subsequently, show waste concentrations beneath the edges of the surface visual plume at different depths.

Vertical settling was approximated by the following equation:

$$W = -\left[\frac{K(\rho(0) + ac - \rho(z))}{\rho_{o(z)}}\right]^{0.5} \qquad (4)$$

This equation is based on a theory of discrete settling[15] as described in Section VIII, Appendix A-3. The constant, A, is empirical and is a function of particle diameter, density and drag coefficient. The constant, α, relates the density of the dispersing plume to the total iron concentration of the diluted waste. It was determined experimentally by sequentially diluting the waste and obtaining the resulting densities. The experiment indicated a linear relationship between density and total iron concentration. Therefore, this constant can be calculated from the concentration and density of the waste and the density of the seawater.

The last row of segments in Figure 8 simulates the settling to and accumulation of waste on the ocean floor. This is done by eliminating the vertical dispersion coefficient at the bottom interfaces across the width of the model, i.e., between segments 97 and 109, 98 and 110, etc. Lateral dispersion coefficients are also eliminated in the bottom row. Thus, the water column is considered as 135 feet deep and waste entering the bottom segments would remain there. Since the model does not include the effects of bottom drift, the assumption of accumulation in the bottom segments is conservative.

LABORATORY VERIFICATION OF SETTLING MODEL

A settling column experiment was conducted to obtain information on the quiescent settling velocities of the waste in seawater. The objective was to verify the mathematical model with data from more controlled conditions and examine the applicability of the discrete settling theory to this particular waste.

The laboratory procedure is given in Section VIII, Appendix A-2. The model verification presented in Figure 9a through 9f is considered reasonably good, although there is a slight discrepancy in the bottom level (refer to Section VIII, Appendix A-2). It is concluded, nevertheless, that the model does sufficiently simulate vertical diffusion and settling under the controlled laboratory conditions to apply it with some degree of certainty to the more complicated oceanic environment.

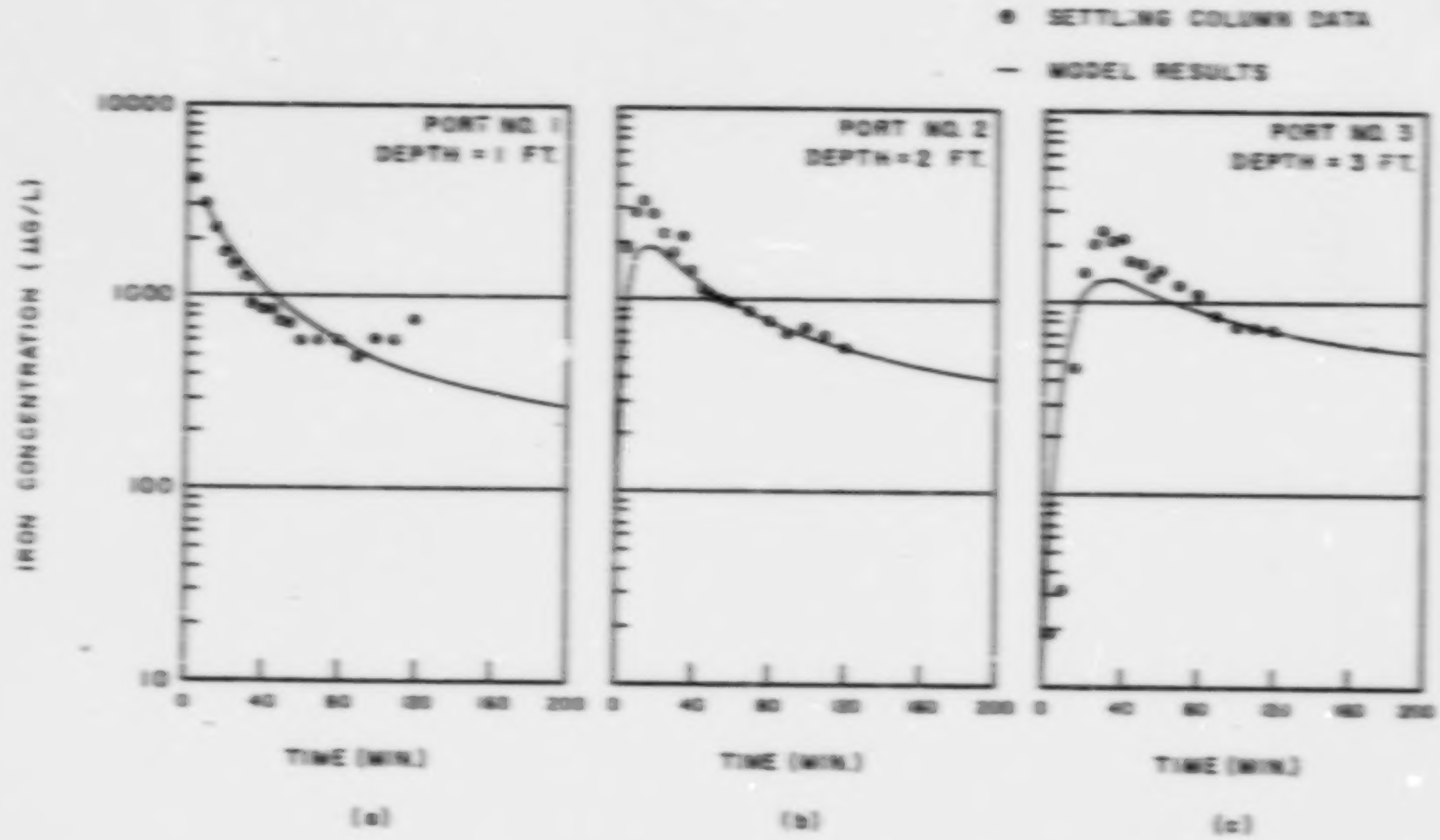


FIGURE 9 (a-c)
SETTLING COLUMN VERIFICATION

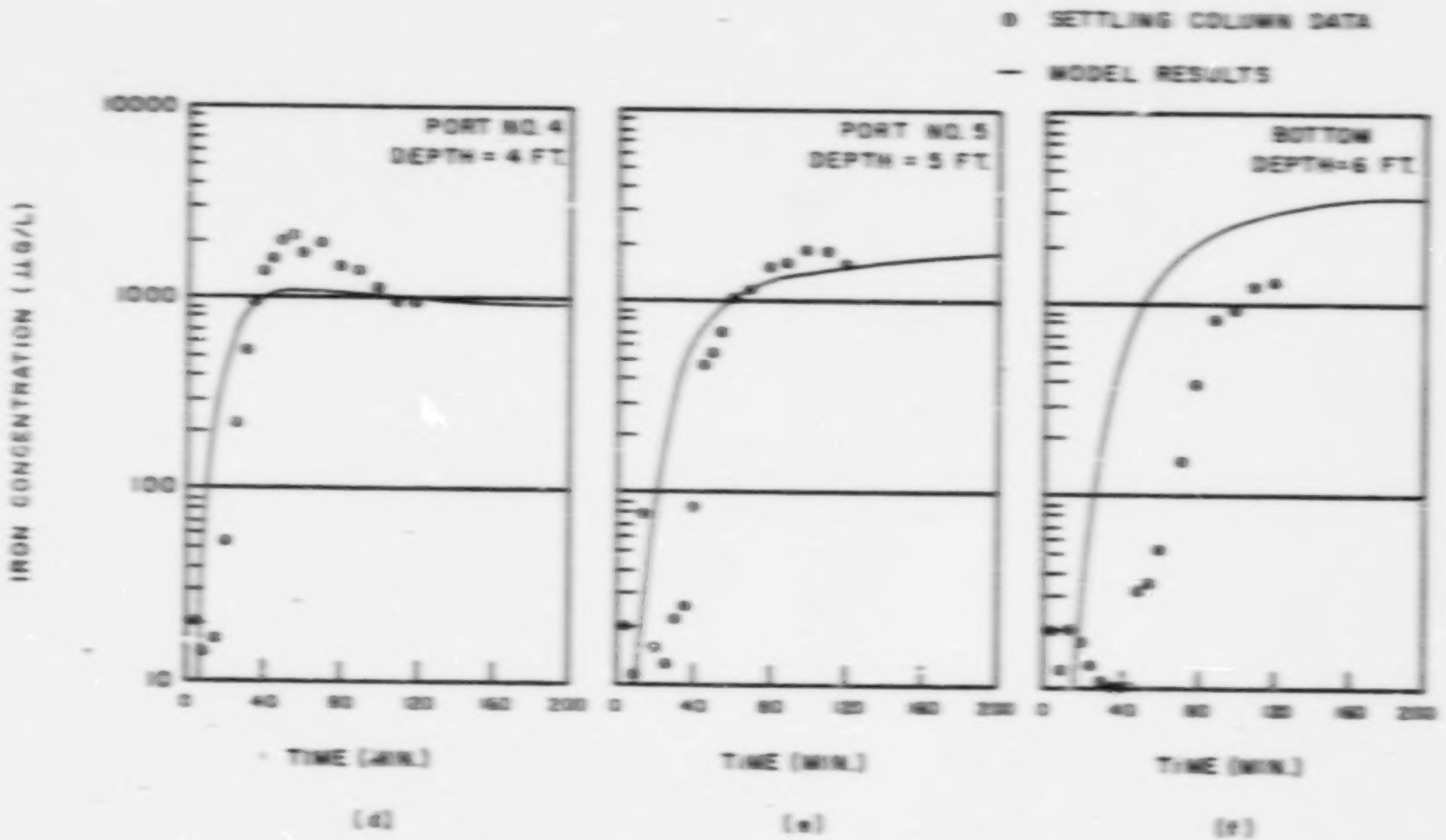


FIGURE 9 (d-f)
SETTLING COLUMN VERIFICATION

VERIFICATION OF MODEL WITH FIELD DATA

General Determination of Parameters

In general, the model's input parameters fall in two categories. The first includes those unique to each dispersion study which can be calculated from field and other data such as the initially diluted waste concentration, the constant, α and the density regime. The second includes the dispersion coefficients and the constant, A, associated with the settling phenomenon. A consistent set of these parameters approximating average conditions, was used for all the dispersion study verifications.

Initial Dilution of Waste

As discussed previously, instantaneous complete waste mixing in the first segment was assumed. The initial iron concentration in the first segment is calculated from the volume and iron concentration of the waste, the barge speed, and the total time of discharge by:

$$C_1 = 1320 \frac{V_b C_b L_1}{U_b T_b V_1}$$

where C_1 = initial iron concentration in first segment (mg/l)

V_1 = volume of first segment (900 cubic feet)

L_1 = longitudinal length of segment (one foot)

V_b = volume of waste in barge ($\approx$ one million gallons)

C_b = iron concentration of raw waste (mg/l)

U_b = barge speed (knots)

T_b = total time of discharge (minutes)

Table 5 shows the initial iron concentration for each dispersion study and the appropriate factors used to calculate it. These concentrations (dilutions of the raw waste by about two orders of magnitude) were input for each verification run.

Settling Constants

Two input constants, α and Λ, are needed to evaluate the settling phenomenon. The constant α (relates the density of the dispersing plume to its iron concentration) experimentally had a linear relationship and could be calculated from the iron concentration of the waste and the densities of the surface seawater and waste by the equation:

$$\alpha = \frac{\rho_w - \rho_o(0)}{\theta_w} \qquad (6)$$

where θ_w = iron concentration of raw waste (mg/l)

ρ_w = density of raw waste (gm/cm^3)

$\rho_o(0)$ = density of surface seawater (gm/cm^3)

The calculated α values were approximately 6×10^{-6} gm/cm^3/mg/l for Cruises K-02-69, K-03-70, and K-05-71, and 4×10^{-6} gm/cm^3/mg/l for Cruise K-04-70. The value for Cruise K-04-70 differed because of higher waste iron concentrations.

The constant, Λ, was obtained through a verification procedure. A value of 100,000 ft^2/min^2 best fit the data of all the dispersion studies.

TABLE 5

INITIAL DILUTED WASTE CONCENTRATIONS USED IN MODEL

Dispersion Study	Raw Waste Iron Concentration (mg/l)	Approximate Barge Speed (knots)	Total Time of discharge (minutes)	Concentration in mixing volume of 900 ft (mg/l)
Cr. K-02-69 Line B	27,900	3	45	302
Cr. K-03-70				
Line A	28,200	6	45	153
Line B	24,700	3	43	282
Cr. K-04-70				
Line A	45,600		65	172
Line B	44,600	6	70	156
Cr. K-05-71	24,600	6	45	134

Density Regime

The dispersion data showed that the water column density regime markedly affected the vertical movement of waste. This effect is incorporated into the model by assuming that the density of the diluted waste depends on the surface seawater density. This simulates an entrainment of the surface seawater in the diluted waste mass with a movement of the entire mass down the depth of the water column. If the density of this waste-seawater mass exceeds that of the water below the thermocline, a positive vertical velocity, per Equation (4), permits penetration of the mass below the thermocline. If the waste reaches the bottom, the last row of model segments simulates settling on the ocean floor and becomes a sink. However, because dispersion constantly decreases the density of the mass, the density of the diluting mass may become less than that of the surrounding seawater below the thermocline. This condition creates a negative vertical velocity and an upward movement of the mass to the vicinity of the thermocline.

Figure 10 shows the seawater density profiles used for each dispersion study verification based on typical salinity-temperature profiles observed during each cruise. The step functions closely approximate actual profiles and simplify computations.

Lateral Dispersion Coefficients

Two independent analytical methods were used to approximate the lateral dispersion coefficient, E_y. The first draws on the theory, summarized by Pearson[16], that turbulent dispersion increases with plume width. The equation:

$$E_y = 0.01(L)^{4/3} \qquad (7)$$

where E_y = lateral dispersion coefficient (cm^2/sec)

L = width of waste plume (cm)

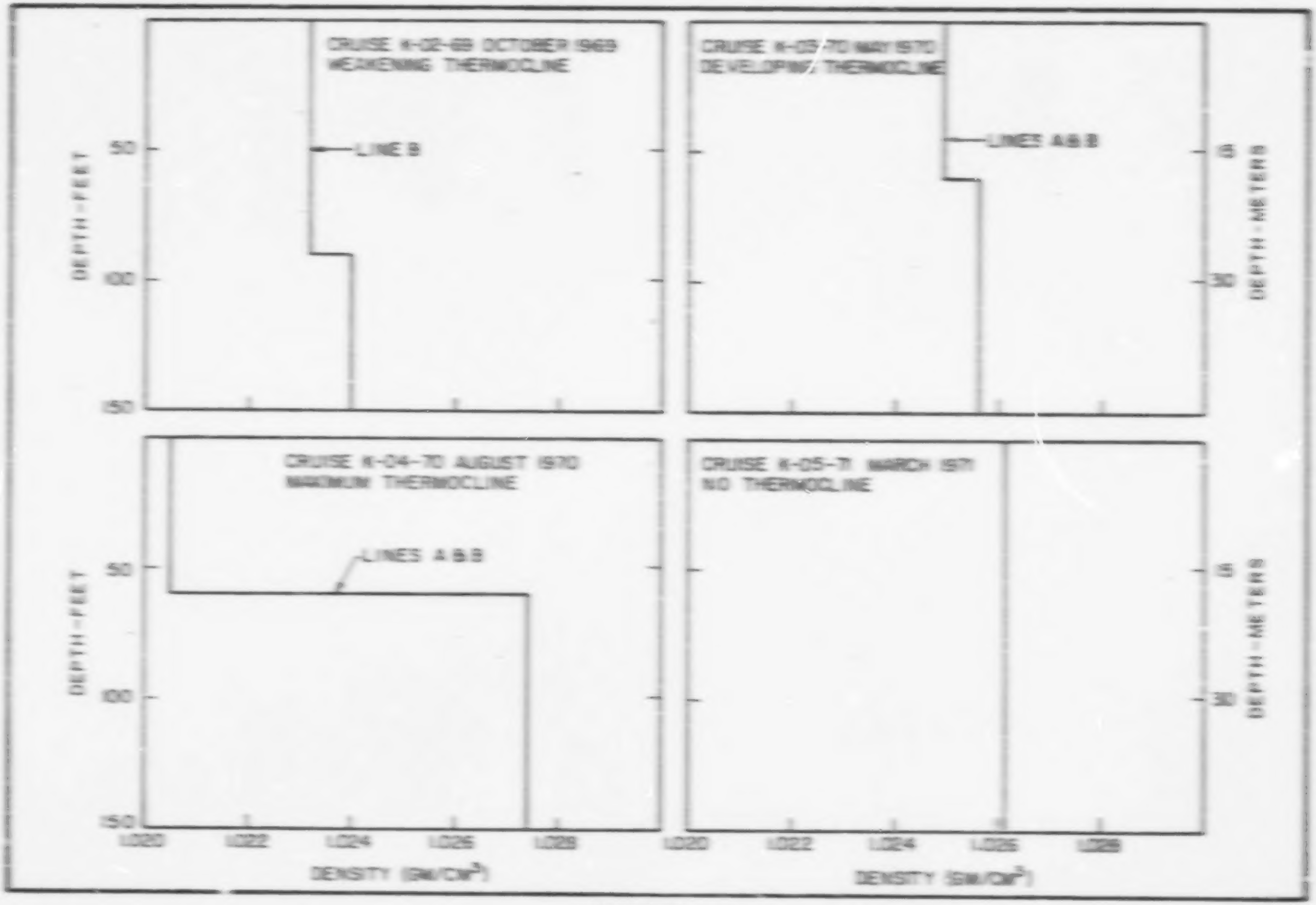


FIGURE 10

DENSITY PROFILES USED IN MATHEMATICAL MODEL yielded dispersion coefficients based on observed widths of spreading plumes. The upper limit of the coefficients based on the widest observed visual plumes are summarized in Table 6.

The second method involves statistical analysis of sea current meter data to obtain dispersion coefficients from random oscillations of the current. The tidal components and other low frequency effects must first be filtered out of the current record. A partial filtering analysis proved unsatisfactory so that a more sophisticated total filtering analysis would be necessary. Nevertheless, some approximate dispersion coefficients calculated from Cruise K-04-70 current data are summarized in Table 7. The dispersion coefficients are separated into north-south and east-west components as a consequence of the analytical procedure.

In summary, these methods provided only a rough first approximation of the lateral dispersion coefficient. The analyses indicate that the lateral dispersion coefficient is of the order of tenths of a square mile per day. A best fit of the data of all the dispersion studies was accomplished using a lateral dispersion coefficient of 0.1 sq.mi./day (30,000 sq.cm/sec.).

Vertical Dispersion Coefficients

Vertical dispersion coefficients were determined on the basis of goodness of fit to the data of all the dispersion studies. Recognising increased vertical dispersion above the thermocline, a value of 100 sq cm/sec. was used above the thermocline and 50 sq cm/sec below. For a homogeneous density regime, the 100 sq cm/sec value was used for the entire depth. These values are consistent with generally reported[16] values for the ocean.

No Thermocline ("Critical" Condition)

The period when ocean density did not change with depth was assumed to be "critical" condition. During that time the possibility of waste settling to the bottom is highest. The period extends from about late October through early April.

TABLE 6

LATERAL DISPERSION COEFFICIENT
AS A
FUNCTION OF MAXIMUM WIDTH OF WASTE PLUME

Dispersion Study	Dispersion Coefficient (E) Square Miles/day
Cr. K-02-69	
Line A	0.02
Line B	0.14
Cr. K-03-70	
Line A	0.17
Line B	0.04
Cr. K-04-70	
Line A	0.48
Line B	0.18
Cr. K-05-71	0.18

TABLE 7

LATERAL DISPERSION COEFFICIENT

Based on Statistical Analysis
of Continuous Current Data

Cruise	Depth	Dispersion Coefficient (E) Square miles/day East-West	Dispersion Coefficient (E) Square miles/day North-South
K-04-76 August, 1970	Top - 15'	0.18	0.56
	Middle - 60'	0.17	0.08
	Bottom - 140'	0.12	0.56

This time of year is considered "critical" because the sedentary benthic community acts to integrate effects and the highest probability of wastes settling to the bottom is during this period. There is no such fixed community at the thermocline to integrate effects. Furthermore, wastes at the thermocline do not accumulate but disperse.

Figure 11 (a), (b), and (c) show the verification of the Cruise K-05-71 dispersion study. The plume centerline iron concentrations (data and model calculation) for the surface and 50-feet and 100-foot depths, are presented. The data fits are considered relatively good considering the inherent problems in sampling and approximations in the model. During the initial minutes, high iron concentrations are computed at the surface as a result of the assumed mixing volume of segment 1. Because of procedural limitations, such values would escape the monitoring. At the end of five hours both the data and the model indicate that the iron concentrations approach background levels over the depth of the water column.

Lateral dispersion results in computed iron concentrations just above 100 μg/l after 90 minutes in segment 60 (depth = 60-75 feet) at the outer extremity of the model. This concentration quickly returns to background levels in this segment. Observed values at the edges of the plume were generally below 100 μg/l.

Iron accumulated in the last row of segments which simulate the ocean floor. The maximum centerline iron concentration computed in the segment just above the bottom was about 650 μg/l. A discussion on the relevance of such results is given in Section VIII, Appendix A-III.

Maximum Thermocline

Cruise K-04-70 occurred during a summer condition of maximum change in seawater density with depth. It was postulated that penetration of waste to the bottom would be least likely under these conditions.

Verification of two dispersion studies (Lines A and F) conducted at the same barge speed was completed with reasonable success.

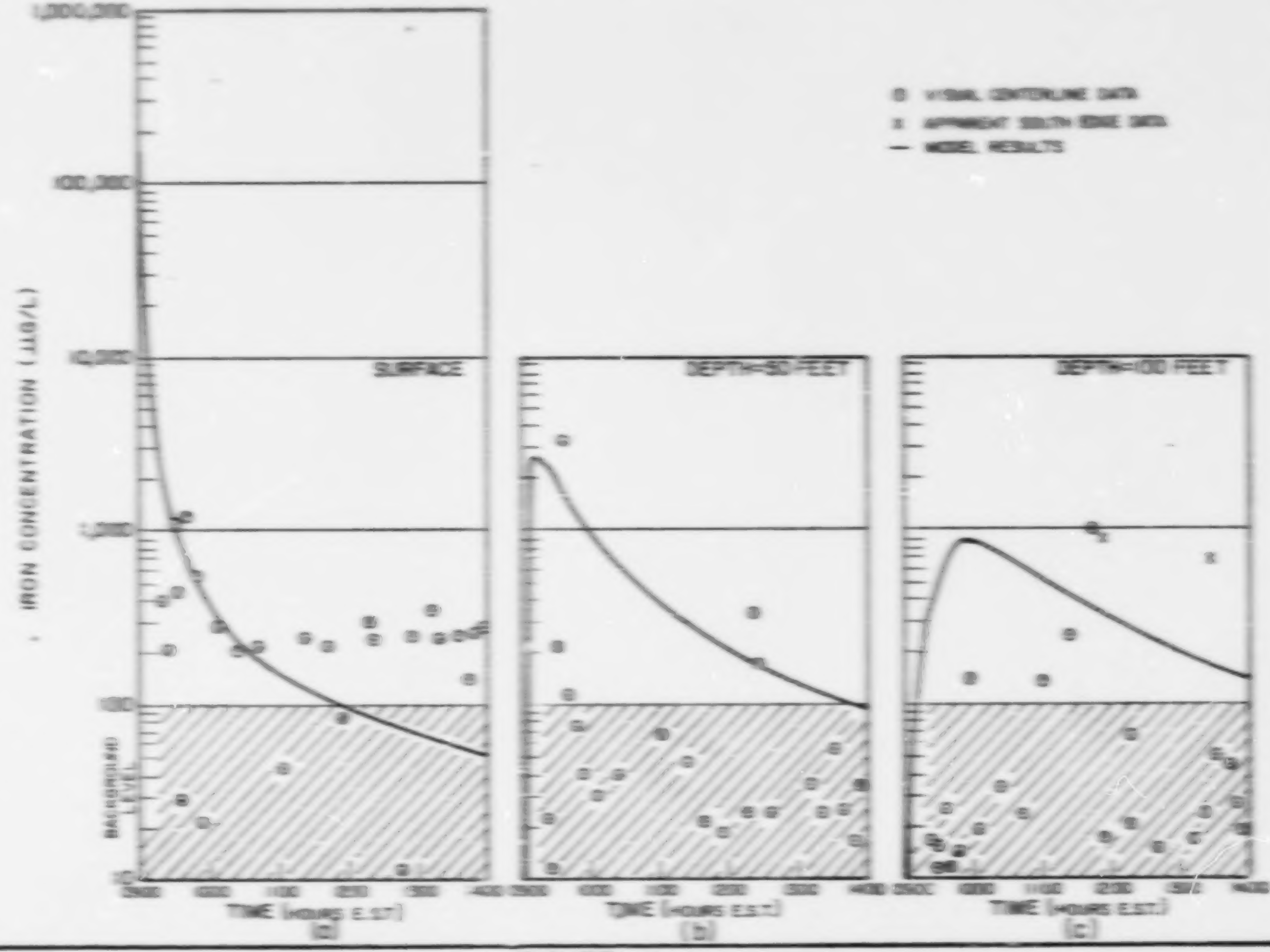


FIGURE 11
VERIFICATION OF CRUISE K-05-71
NO THERMOCLINE ("CRITICAL" CONDITION)

Figures 12 (a), (b), (c), and (d) show a typical verification of maximum thermocline conditions. The centerline iron concentrations (actual data and model) for the surface, 25-foot, 50-foot, and 75-foot depths are presented for Line B. The effect of the directional current shear during this dispersion study is especially demonstrated in Figure 12 (c), where significantly higher iron concentrations were observed at the 50-foot depth south of the visual centerline of the surface plume. These values are indicative of the actual centerline of the waste field at that depth. For both Lines A and B the observed data and the computed results show that iron concentrations below the thermocline were less than the background level (100 µg/l). The model predicted, for both dispersion studies, essentially no iron below the level of Segments 49 through 60 (depth = 60-75 feet) where the density change first occurs. Therefore, only 75 feet of the water column was available for mixing. Thus, lateral mixing is the predominant factor in diluting the waste. After forty minutes, iron concentrations over 100 µg/l were computed for both model runs in segment 48 (depth = 40-60 feet) at the outer extremity of the model. On the other hand, segment 12 at the surface of the outer extremity of the model never reached concentrations above 100 µg/l. Therefore, the model shows a rapid settling of the waste to the area of the thermocline with lateral dispersion predominant at this level. The observed dispersion data is generally concurrent.

The model shows high iron concentrations still present in the area of the thermocline at the end of four hours (Figure 12 (c)). This was more obvious in the data observed in Line B. At that time, the concentrations decrease was relatively slow, indicative of a substantially longer period required for iron concentration near the thermocline to return to background levels. The model assumes a constant lateral dispersion coefficient. During the initial hours after discharge, when the plume is relatively narrow, this assumption is valid. However, as the plume spreads, larger eddies are probably encompassed and turbulent fluctuations increase. The overall circulation pattern, as well as the directional current shear, ever increasingly affect the dispersion especially during the later periods after discharge. The model is therefore considered conservative with respect to the overall time required for a return to background iron concentrations.

Mild Thermocline

Four dispersion studies were conducted under conditions of a mild thermocline: two (Cruises K-02-69) under a weakening thermocline and two (Cruise K-03-70) under a developing thermocline. Three of these have been reasonably verified. Line A, Cruise K-02-69, was eliminated from verification analysis because of the poor data obtained (refer to Section VIII, Appendix A-1). Figures 13 (a), (b), and (c) show typical verification. The visual centerline iron concentrations (actual data and model) for the surface, 25-foot and 50-foot levels, are presented for Cruise K-03-70, Line A, conducted at the normal barge speed of six knots.

When compared to Cruise K-04-70 (maximum thermocline) simulations the computed values under a mild thermocline show almost as stringent spatial barriers to waste settling even though the density differences are comparatively smaller. No iron concentrations above background levels were computed below the thermocline for any of these studies. Because of decreased barge speed (three knots) for Cruise K-03-70, Line B, the initial concentrations put into the model were double those calculated for Line A of that cruise. This produced higher computed concentrations for Line B in the vicinity of the thermocline, but not high enough to penetrate. However, there was observed evidence of waste penetration through the shallow mild thermocline during Cruise K-03-70, Line B, in that some iron concentrations in excess of 100 μg/l were measured at the 100-foot depth during the initial sampling period. This indicates that the model tends to overestimate the degree of waste stratification during a shallow mild thermocline condition. As a result, the model is probably conservative with respect to the time necessary for the water column to approach background iron levels. Nevertheless, the majority of the data does indicate that even a mild thermocline has a significant effect on the settling of the waste, especially under normal (six knots) barge speeds, as demonstrated by the data of Line A. The model is, therefore, in general agreement with the overall conclusion that the waste, as measured by iron, does not reach the ocean floor in concentrations above background levels at normal barge speeds.

The model results for Line B of the October Cruise K-02-69, indicate a more rapid decrease in the iron concentrations, especially near the surface. This results from the large mixing volume available because of the deeper thermocline.

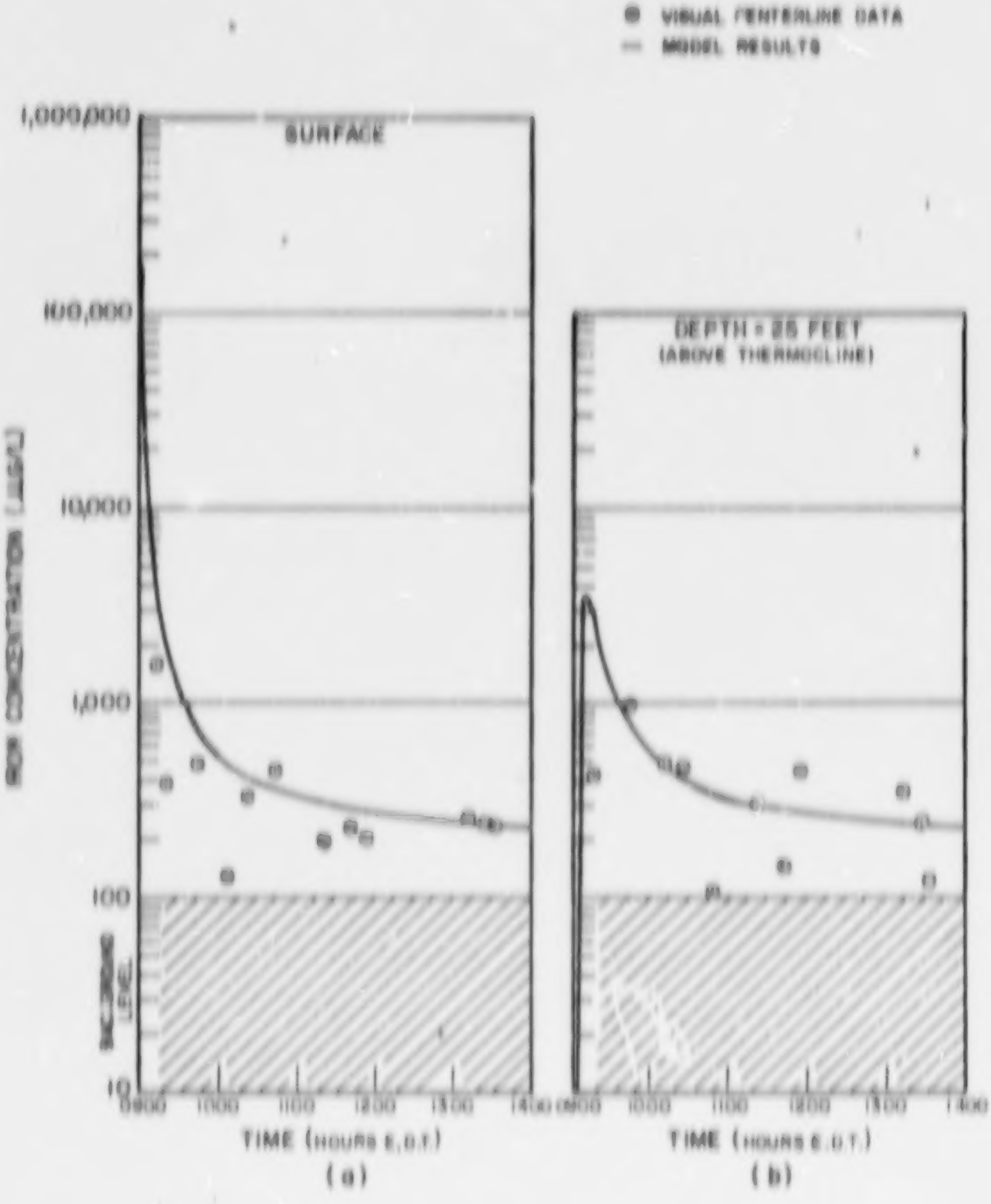
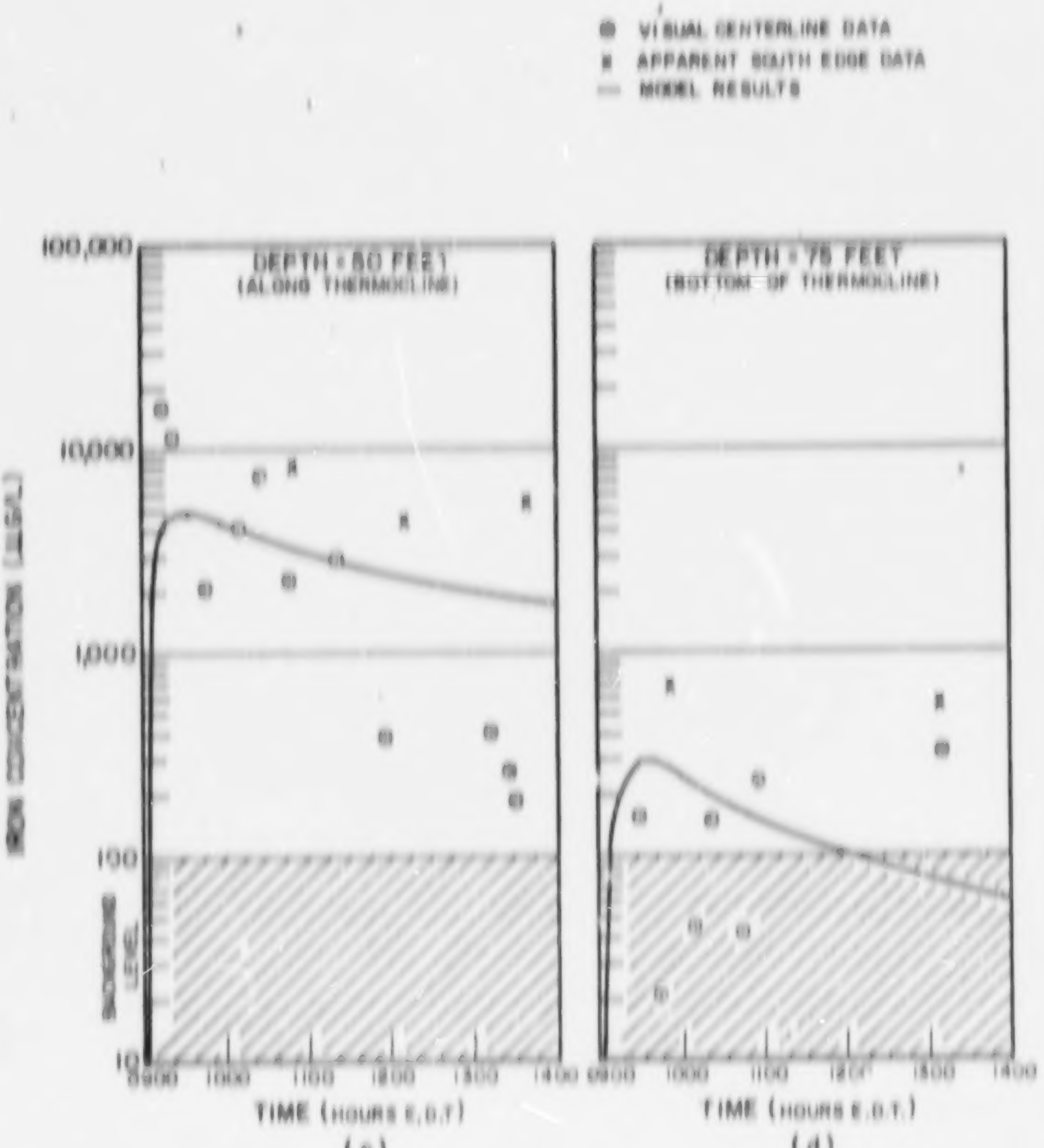


FIGURE 12 (a and b)

VERIFICATION OF CRUISE K-04-70 LINE B

MAXIMUM THERMOCLINE



(c)

(d)

FIGURE 12 (c and d)

VERIFICATION OF CRUISE K-04-70 LINE B

MAXIMUM THERMOCLINE

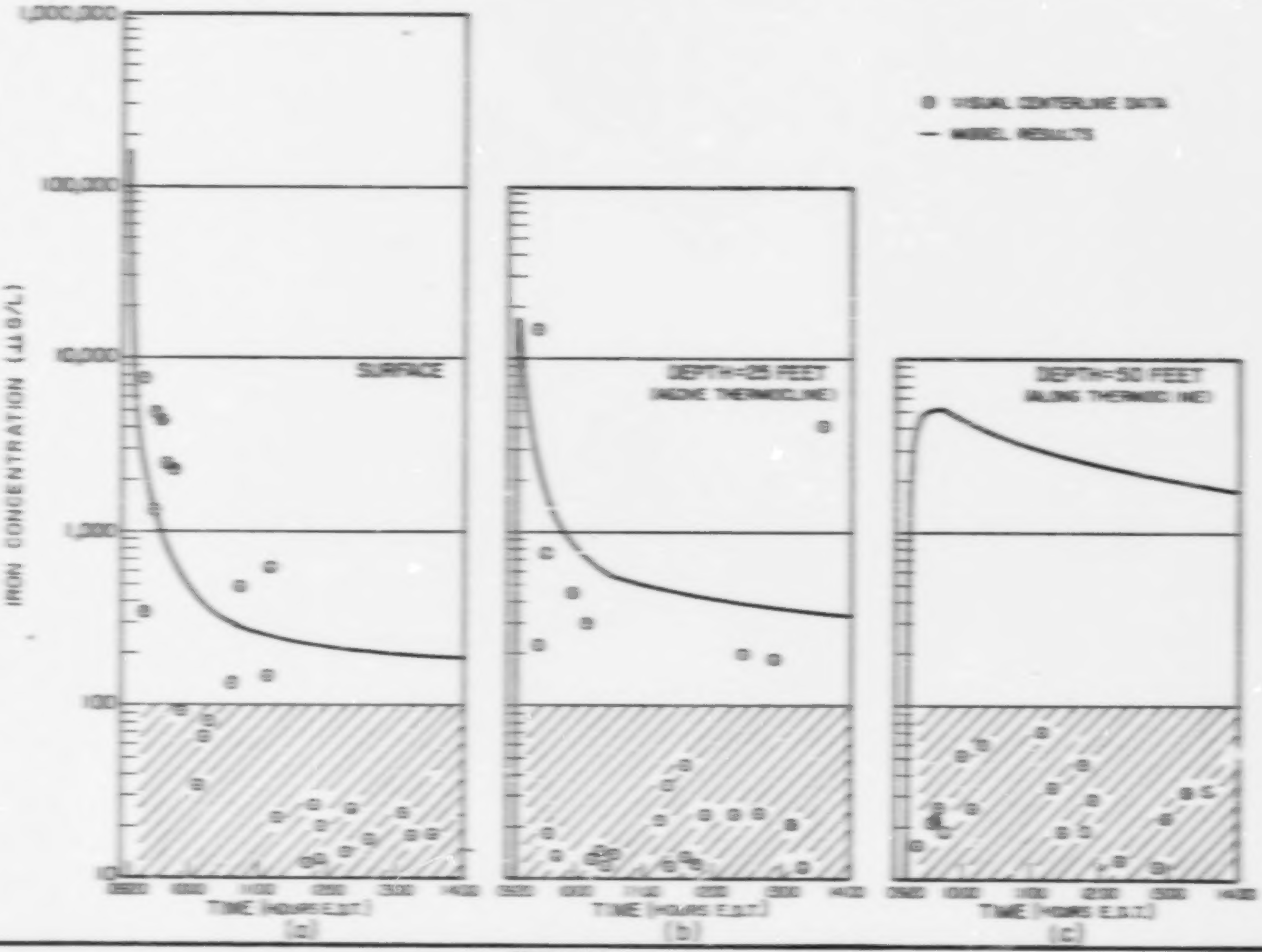


FIGURE 13
VERIFICATION OF CRUISE K-03-70 LINE A
MILD THERMOCLINE

Conclusions on Validity

The validity of a mathematical model, depends on the accuracy of the data collected. As pointed out previously, there were inherent limitations and difficulties encountered in sampling in the oceanic environment. For instance, the location of the plume was based solely on visual approximations. Directional current shear in the area, as demonstrated by the current data, presents the possibility of missing the waste at the lower depths. Sampling on the edges and outside of the plume attempted to minimise this possibility. The mathematical model simulates the settling and dispersion of a specific cross-section of the waste. This could only be approximated by the sampling routine. Safety precautions prohibited sampling immediately after discharge. This eliminated some useful information on waste concentrations during the first few minutes after discharge.

The mathematical model incorporates some simplifying approximations. Lateral dispersion coefficients are assumed constant both spatially and temporally and independent of the spreading plume width. The diluting effect of directional current shear is not incorporated into the model. However, the above approximations make the model somewhat conservative. In addition, vertical settling of the waste is approximated by a settling theory developed for discrete particles. Laboratory verification proved this approximation to be satisfactory.

Given the field limitations and mathematical approximations, the verification of the various dispersion studies is considered reasonably good. A consistent set of dispersion and settling parameters was utilised for all of the dispersion studies verified, thus approximating average conditions over the year. The unique inputs and density regimes used in the model were based on observed data from each survey.

Comparison of model results with field data indicated reasonable agreement. Rigid statistical analyses were considered of little practical use because (a) the variability of the data was expected to be substantial due to inherent difficulties and limitations of marine sampling, and (b) the model was formulated to predict order-of-magnitude concentrations. Verification of such complex models under the various oceanic conditions encountered would be expected to be difficult. It is significant that the model does simulate the first hour's concentration of the waste within an accuracy of about 1/2 order-of-magnitude after a dilution of the barged waste by about six orders-of-magnitude.

In general, the model indicates the vertical density gradient has a pronounced effect on the dispersing waste concentration, as measured by iron. The model shows that, under normal barging speeds, the waste does not penetrate the vicinity of the thermocline even during the spring and fall conditions when the thermocline is relatively mild. This concurs with the observed data, although the condition is more stringent in the model.

In summary, model verification has been approximately accomplished for the various dispersion studies with a consistent set of dispersion and settling parameters, along with unique inputs and density fields calculated for each survey. The model is considered to form a useful basis for a first estimate of the effects of waste discharge on the vertical and horizontal distribution of a conservative substance. As such, the model provides a means for predicting the location and concentrations of iron as an indicator variable of the waste discharge. The model may therefore be applied to the defined "critical" period in order to evaluate the amount of waste which reaches the ocean floor. The model can then be used to estimate the effectiveness of different methods of discharge.

SECTION IV-C

APPLICATION OF MODEL

A critical condition is assumed to occur during periods of a homogeneous density regime when the amounts of the settleable constituents of the waste, specifically iron, could reach the bottom is at a maximum. Some threshold concentration that will affect the benthic organisms has been assumed to be a criterion in applying the model. It is probable that in determining this threshold level, the waste concentration in the immediate overlying water column will be used rather than some measure (e.g., depth of precipitated iron) of the actual accumulation of wastes on the ocean floor.

The controllable parameter that affects the amount of waste reaching the bottom area is the "near-field" waste concentration (initial concentration is segment 1 of the model) immediately after discharge which is inversely proportional to barge speed. In addition, the mechanism of discharge affects this concentration. For example, use of an alternate diffuser system would reduce this initial concentration.

The mathematical model was applied to a homogeneous density regime at various initial diluted waste concentrations ranging from 10,000 to about 175,000 μgFe/l. The upper limit represents the approximate maximum concentration under present barging procedures. Figure 14 is a plot of the initial concentration in segment 1 against the resulting iron concentration in the last centerline segment above the "bottom" (segment 97). The values for segment 97 represent the maximum computed for the various initial concentrations. The time to reach those peak values varied inversely with the initial concentration. This results from the combined effect of the nonlinear settling velocity and dispersion. At an initial concentration of 10,000 μgFe/l the peak computed concentration in segment 97 was reached in about five hours.

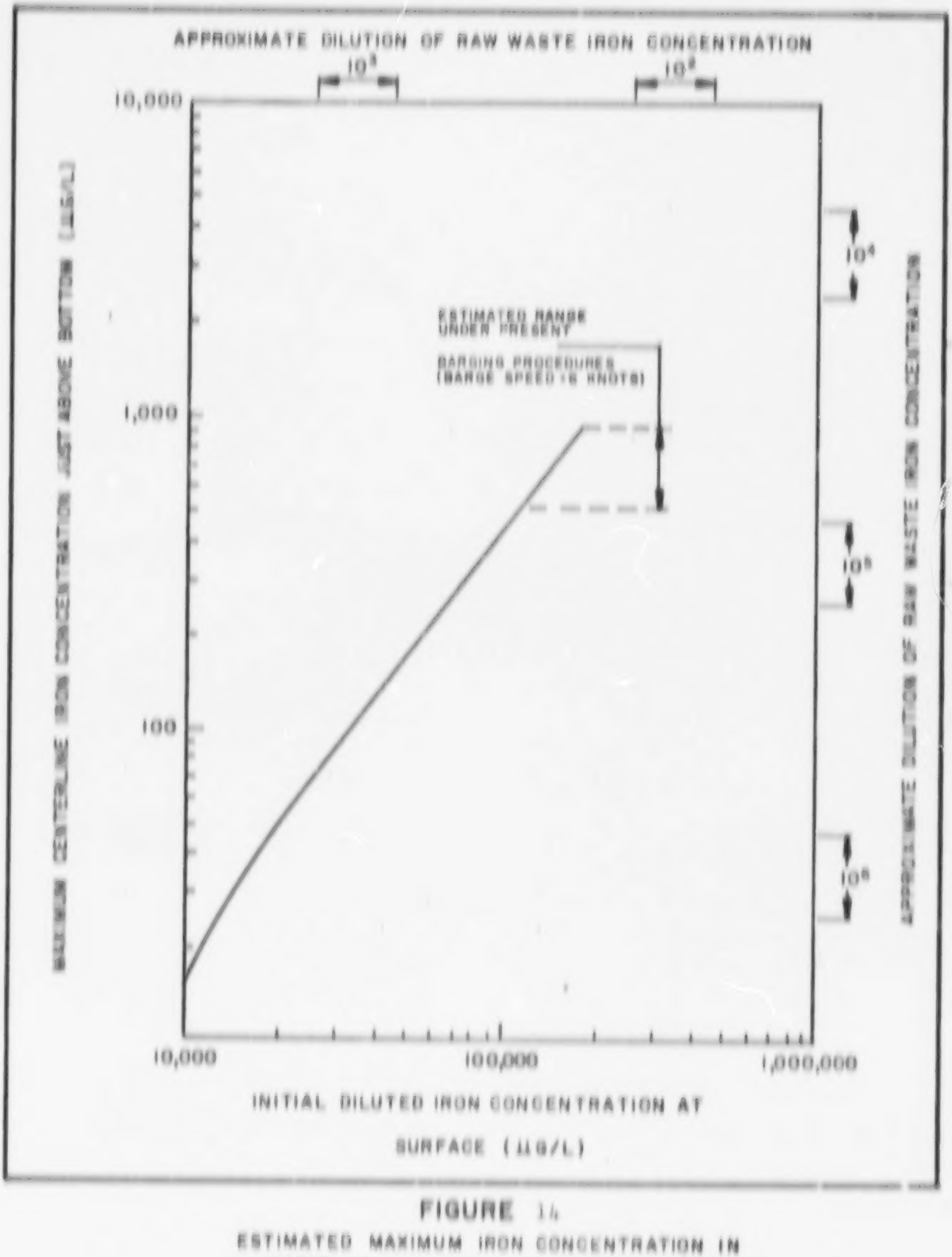


FIGURE 14

ESTIMATED MAXIMUM IRON CONCENTRATION IN
WATER COLUMN JUST ABOVE OCEAN BOTTOM
UNDER "CRITICAL" CONDITION

As shown in Figure 14, the model predicts that, under present barging procedures, the centerline iron concentrations just above the bottom ranges from about 500 to 900 μg/l, a dilution of the raw waste by more than four orders of magnitude. The model also predicts (Figure 14) that, if the initial diluted iron concentration were reduced to less than 35,000 μg/l, the resulting centerline iron concentration at this depth would be less than 100 μg/l. However, if the accumulation of any wastes is considered undesirable, the model shows that at an initial diluted iron concentration of about 10,000 μg/l, no iron reaches the last row of segments simulating the ocean floor. This represents about an order of magnitude reduction in the initial diluted iron concentration from what is presently practical.

It is concluded from these results of application of the model that if an approximate 1/2 to 1 order of magnitude reduction in the initial "near-field" waste concentration can be accomplished, the waste, as measured by iron, will probably not reach the ocean bottom in concentrations above background levels. Under less critical times of the year (e.g., developing thermocline), the situation will be more favorable. The reduction might be accomplished by an alternate discharge procedure.

SECTION IV-D

SUMMARY

WATER QUALITY BEFORE AND AFTER WASTE DISCHARGE OPERATIONS

Water quality data obtained in the disposal area during the five background studies indicate no general trend attributable to the disposal operations. Concentrations of iron obtained during the background study of Cruise K-01-69, conducted prior to the initiation of waste disposal in the primary area, were not measurably different from those obtained during four later studies. During Cruise K-01-69, iron concentrations at the five primary background stations ranged from 31 to 113 µg/l, while for the remaining four cruises they ranged from less than 10 to 110 µg/l.

Other chemical analyses of the water column were generally typical of the ocean in this geographic location and no substantial change was observed during the disposal operations. Dissolved oxygen was generally at or near saturation throughout the water column during all background studies. Alkalinity at the five primary background stations varied from about 114 to 125 mg/l as $CaCO_3$. Values of pH averaged 8.2 (range: 7.8 to 8.8). Variations in nitrogen and phosphorus levels were attributed to expected seasonal changes. Light extinction coefficients in the study area averaged about 0.03/foot during most of the background studies, indicative of relatively clear water.

Comparison of the two control stations with the three stations in the disposal area showed no measurable difference in water quality. The chemical data for the water column were generally consistent with what would be expected for the ocean area under study. No persistent change in water quality was detected during the surveillance program. It is, therefore, concluded that the disposal operations did not contribute to any persistent change in the background water quality of the area under investigation over the length of the sampling program.

OBSERVED DISPERSION AND SETTLING OF WASTES

The dispersion data indicated that initial mixing and dilution of the waste after discharge is relatively rapid. In general, the raw waste iron concentration was diluted by three to four orders of magnitude during the first thirty minutes after discharge. The highest iron concentration recorded in the wake of the barge was about 24 mg/l, compared with 25,000 mg/l in the waste. The rapid dilution of waste as measured by pH and acidity, was even more substantial. During the first ten to twenty minutes after discharge, the raw waste hydrogen ion concentration decreased by about six orders of magnitude and a reduction in the raw waste acidity by about three to four orders of magnitude were generally observed. The ocean's alkalinity and pH returned to background levels within approximately one to four hours after discharge for most of the dispersion studies. Since pH and alkalinity are functions of chemical equilibrium as well as the physical dispersion and settling phenomena, this rapid return to background levels was expected. On this basis, the chemical formation of the ferric iron floc must also have been generally completed during this period. As a result, any persistent iron concentrations measured at times significantly after this initial mixing period are probably indicative of a suspended ferric hydroxide floc in an otherwise neutralized oceanic environment with respect to acidity.

The thermocline markedly affected the settling characteristics of the waste. During the summer condition of maximum thermocline, the wastes did not penetrate below the vicinity of the thermocline. Even during the spring and fall periods of relatively mild thermoclines, penetration of the waste below the vicinity of the thermocline was not observed at normal barging speeds. During homogeneous density regimes, typical of late fall and winter, part of the dispersion waste field, as measured by iron, can reach the ocean bottom under present barging procedures. Since the benthic community is relatively non-motile (compared to organisms in the overlying water column) and acts to "integrate" exposures, winter can be defined as a "critical"period.

During summer, a decreased mixing volume above the thermocline is available for waste dilution. As a result, iron concentrations in the water column, especially in the vicinity of the thermocline, remain for longer periods. Then lateral dispersion becomes the predominant diluting phenomenon. As the plume spreads, dispersion of the wastes probably increases because of larger eddies as well as current directional shear. Analyses of the observed data of all the dispersion studies indicate that a maximum time of from approximately five to as high as twenty hours may be required for the total iron concentrations in the water column to return to background levels with the longest time required in summer. Since waste acidity is rapidly neutralized, the persistent iron concentrations, especially for the longer periods, are most probably solely indicative of a suspended ferric iron hydroxide floc in an otherwise neutralized ocean environment. However, this floc may affect light penetration, even at concentrations near background levels.

APPLICATION OF MODEL TO OTHER BARGING SITUATIONS

The generalized model developed may be used for a first estimate of the lateral and vertical distribution of a conservative substance in the marine environment. An option to include decay coefficients is available. Thus, the model may be applied to simulate dispersion of other wastes discharged to the ocean. A reevaluation of certain parameters, e.g., the settling phenomena, would be necessary. Therefore, application of the model to other wastes must be preceded by field dispersion and settling studies (supplemented by laboratory investigations) to provide the necessary data for verification analyses.

SECTION IV-E

GENERAL CONCLUSIONS AND RECOMMENDATIONS ON DISPERSION OF WASTES

CONCLUSIONS

1. The initial mixing and dilution of iron-acid waste in the ocean after discharge behind a moving barge is relatively rapid. In general, the wastes were diluted by about three to four orders of magnitude during the first thirty minutes after discharge. Ocean water alkalinity and pH generally returned to normal background levels within one to four hours after exposure to a waste acid concentration of about 20%.

2. The disposal operations did not contribute to any persistent change in the water quality of the area under investigation over the length of the surveillance program.

3. Presence of a thermocline (boundary between warm water over cold) affects the settling characteristics of the waste. During summer, when a maximum thermocline exists, the wastes do not penetrate below the vicinity of the thermocline. Even a relatively mild thermocline (late spring and early fall) does not permit waste penetration below the vicinity of the thermocline under normal barging procedures.

4. Under a homogeneous density regime (late October to early April in the study area) a portion of the waste field can reach the ocean bottom under present barging procedures. Since the benthic community is relatively nonmotile compared to organisms in the overlying water column and can "integrate" effects, this period was considered "critical".

5. Although the summer thermocline minimizes the chance of wastes reaching the ocean floor, it maximizes the time needed for the water column to return to background levels of iron because of the decreased mixing volume available. During summer, up to twenty hours are required for the water column to return to background levels. In contrast, wastes return to near background levels over the depth of the water column within five hours after discharge during winter (homogeneous density). Waste did not accumulate at the thermocline.

6. Continuous current data showed a rotary tide in the study area with substantial directional shear over the depth of the water column. Direct on-shore currents are relatively minimal. There is a general southwesterly drift trend in the area. Surface current reversal to the northwest were observed during late spring and summer. The maximum net drift velocity recorded was approximately 8.7 nautical miles per day (0.36 knots).

7. The calculated maximum horizontal spatial range of the waste (defined by above background iron concentrations) extends about ten nautical miles from the discharge point and would probably occur during the summer. The general movement of the waste field is to the southwest, except during reversals (late spring and summer), when the wastes above the thermocline would move toward the northwest. Interference with near-shore activities is highly unlikely.

8. Since the acidity of the waste is rapidly neutralized, any persistent iron concentrations present at time significantly after the initial mixing period, would probably be in the form of a suspended ferric iron floc in an otherwise neutralized environment. The floc may, however, affect light penetration even at iron concentrations near background levels.

9. A specially developed time-variable mathematical model can simulate the lateral and vertical movement of the waste, with iron as a conservative tracer. Laboratory settling data permitted verification of a waste settling model. Overall approximate model verification from field dispersion studies was based on consistent sets of dispersion and settling parameters for all tests plus unique inputs and density fields observed on each survey. The model provides an analytical

framework which sufficiently duplicates observed data and allows, with some confidence, predicting the dispersion and settling of the waste, as measured by iron, under alternative discharge schemes.

10. Model simulations of barging procedures indicate that, during a homogeneous density regime, maximum centerline iron concentrations in the water column just above the ocean bottom range from approximately 0.5 to 0.9 mg/l (Fe). During periods of developing thermoclines, the model indicates that under present barging procedures, the waste will not reach the ocean bottom in concentrations above background levels.

11. The model predicts that, if the "near field" waste concentration is reduced by about a half to one order of magnitude, the waste discharge will probably not reach the bottom of the ocean in concentrations above background levels during the "critical" period.

12. The model developed for this investigation is a generalized model which may be used for a first estimate of the effects of a waste discharge on the lateral and vertical distribution of a conservative or non-conservative or non-conservative substance in the marine environment. As such, the model may be applied to municipal and other industrial wastes. However, application of the model to other wastes must be preceded by field dispersion and settling studies (supplemented by laboratory investigations) to provide the necessary data for verification.

RECOMMENDATIONS

1. Continue a surveillance program to assure discovery of any long-term changes in water quality. Water quality studies could be limited to two per year (end of the winter and summer). Data collected should be as in past "background" studies. Since iron concentrations above background levels may persist for as long as twenty hours after discharge and extend further to the southwest or northwest, add additional sampling stations within a radius of about ten nautical miles northwest, west, and southwest of the disposal area.

2. This investigation determined that, under present barging procedures, a portion of the waste can reach the ocean bottom during homogeneous density regimes. Calculations show that, if the initial "near-field" waste concentration were reduced by about a half to one order of magnitude, the waste (iron) would not reach the ocean floor in above-background concentrations. If minimizing waste concentrations at the ocean floor is desired, field trials of this estimate are recommended before permanent modification of barging procedure or barge design is made. Field trials might be done by using a throttling mechanism. If the present operating barge speed is maintained, this would decrease the initial diluted concentration of the waste and the resultant bottom concentrations.

SECTION V

EFFECTS ON MARINE BIOTA

This Section presents information on the biological effects resulting from the introduction of sulfuric acid-iron sulfate waste into the localized area of the marine environment off the coast of Delaware. The University of Delaware College of Marine Studies designed and conducted this portion of the study to provide background information and monitor any changes in the nature and diversity of the marine biota in the area receiving waste addition. Five sampling stations (numbers 2, 4, 5, 6, and 8 in Figure 1) were established within or adjacent to the disposal area. Station 5 was at the center of the disposal area. Station 2 was considered a potential control station and is 3.5 nautical miles north of the northern boundary of the area. Station 8 is 3.5 nautical miles downstream from the southern boundary of the area. Stations 4 and 6 lie at the eastern and western edges of the disposal rectangle. Coordinates of these stations are found in Table 1.

The University of Delaware sampled the marine biota and bottom sediment during the predisposal and four seasonal surveys carried out by Hydroscience, Inc., as reported in Section IV. In addition, the University made several surveys (see Table 2) to obtain more complete data on seasonal effects upon the biota. These surveys concentrated on Stations 2, 5, and 8.

This Section evaluates:

1. the nature and abundance of the plankton, nekton, and benthic biota,
2. the size and composition of bottom sediments,
3. those benthic organisms which might be used as indicators of waste effects, and
4. water movement in the disposal area.

SECTION V-A

METHODS AND MATERIALS

One of the principal themes of this study was to establish whether buildup of waste material would occur in the disposal area between disposal operation and, if so, observe any changes in composition of the plankton community. A station-based sampling scheme was used for this assessment.

The initial background survey was made from the 65-ft R/V Kyma. As this vessel was not rigged for heavy trawls, the R/V Pathfinder was used for heavy benthic work and the R/V Albatross IV for sampling with a commercial hydraulic clam dredge. After the initial survey, all field work was done from the R/V Skimmer and R/V Kyma.

Water samples were taken at 5 or 6 depths from surface to bottom in 1200 ml Teflon®-coated Nansen bottles. Temperature was determined with a bathythermograph (BT) and paired, protected, reversing thermometers on Nansen bottles. Dissolved oxygen was measured by a modified Winkler method,[18] and oxygen saturation values were obtained from the nomogram of Green and Carritt[19]. The pH of water and bottom sediment was measured with a single combination electrode on a Sargent digital pH meter. Light extinction was estimated by lowering a 30-cm diameter Secchi disc. Salinity was measured by electrical conductivity on a Bissett-Berman model 6220 salinometer. Residual surface and bottom currents were estimated by returns of ballasted drift bottles and sea-bed drifters.

Phytoplankton samples were obtained from the surface water of each station in a 5-minute tow with a 50-cm diameter unmetered net of #20 mesh (0.069 mm aperture). Zooplankton were collected with a 30-cm diameter, metered, Clarke-Bumpus plankton sampler, fitted with a #6 mesh net (0.241 mm aperture). Two 15-minute tows were made at each station, one at the surface and one below the thermocline (25 meters, if no thermocline present). Towing depth was verified with a Benthos time-depth recorder attached immediately under the net. Plankton samples were preserved in buffered formalin.

The laboratory procedure for phytoplankton collections consisted of thoroughly mixing the sample and withdrawing aliquots for identification of species present. The sample was mixed again and a 1-ml aliquot withdrawn and placed in a Sedgwick-Rafter chamber. Five random counts within the counting chamber were made using a field delineated by a Whipple ocular micrometer grid. These counts were transformed into percent composition and an average of the five fields was taken. Species were expressed as either percent composition or as trace if the average relative abundance was less than one percent. Individual cells were counted in those species occurring in chain forms.

The laboratory procedure for zooplankton samples consisted of large specimen removal (e.g., medusae) followed by aliquot removal (usually 2 ml) with a Stempel pipette for counting and identification. The aliquot was usually 0.4 - 0.8% of the sample volume. After aliquot removal, the sample was split in a Folsom plankton splitter to a 1/2, 1/4, or 1/8 fraction shaped steel frame. Towed behind the vessel at a very slow speed, the SBT qualitatively sampled the epibenthos and upper infauna. If the net contained much sand the contents were sieved through a 2-mm standard geological sieve and the coarser fraction saved. Large pelecypod shells were identified and recorded, and all other biota were preserved in 90% ethanol for later identification.

The hydraulic clam dredge was of the standard commercial type.

Sediment coring was attempted during the predisposal survey with a gravity core with 12-in barrel. Repeated attempts failed to obtain a core from the sandy sediment and this gear was not used thereafter. Sediment samples obtained from the Peterson grab sample were sieved in a standard sieve set. Sediment iron was determined on August 1970 sediment samples by a standard ore analysis[20] for Fe_2O_3.

Visual observation of the bottom was accomplished in the predisposal survey of May 1969 with an underwater television camera with a monitor and videotape recorder on the boat. In July 1970, underwater photographs were taken at Stations 2, 5, and 8. An EG&G vertical mounted camera was used on Stations 5 and 8. Station 2 was shot with an

Alpine camera mounted at an angle of about 40° from the vertical. Approximately 20 photographs were taken at each station at night.

SECTION V-B

HYDROGRAPHIC DATA

WATER CHEMISTRY

Hydrographic data were obtained from the disposal area in July, October, and November 1970, and January and May 1971 (see Section VIII, Appendix B-1). Such data were collected at five additional times between May 1969 and March 1971 by Hydroscience from R/V Kyma.

Data from the University of Delaware cruises show surface temperatures ranging from 23° during July to 7° C in January. Bottom temperatures were at a minimum in July (6.8°) and maximum (14.6°) in November. (Subsequent sampling has shown bottom temperatures as high as 19° in October at Station 5 immediately after thermocline destruction.) A very well developed thermocline was found between 20 and 26 meters during July and October, but was destroyed by mid-November. Thermocline formation was well underway by late May. Salinity was found to be relatively uniform throughout the year, ranging from 31.2 to 33.1 parts per thousand (°/oo). The increase of salinity with depth varied from 0.3 to 1.1°/oo.

Dissolved oxygen was at or above saturation above the summer thermocline and throughout the water column in January. It was about 2.5 ml/l below saturation in water below the summer thermocline. In November 1970, dissolved oxygen was found to be markedly low (2 - 3 ml/l below saturation) at all stations from surface to bottom. An intense phytoplankton bloom was underway in the recently overturned water, and the oxygen depletion may have been due to respiration of large numbers of bacteria associated with the bloom. As the most recent waste discharge was

2-1/2 days prior to the dissolved oxygen measurements, it seems unlikely that the waste could account for this oxygen depletion.

The pH of the water normally ranged from 7.9 - 8.2 although values of 7.3 were found in bottom water at Station 2 in October, 1970. The low ph of the entire water column at Stations 2 and 5 of this survey might be related to waste disposal. A discharge operation occurred at 0835 on the day the samples were taken. The time interval between disposal and station sampling was 7 to 11 hours. However, these pH values are not consistent with the data of May 27, 1971, in which normal pH values were found in samples taken 6 to 13 hours after a disposal operation.

Secchi disc readings were maximum (17 meters) in October.

SURFACE AND BOTTOM CURRENTS

Residual surface and bottom currents were determined from returns of ballasted drift bottles and sea bed drifters. In May 1969, drops were made at 4 stations between Cape Henlopen and the disposal site (Stations A-D) and at the 5 study stations around the disposal site (Table 8). Additional drops were made in the disposal area in October 1969 and August 1970. Recoveries from the 5 study stations ranged from zero to 12% for bottom drifters, and from zero to 10% for surface bottles. The 4 stations between the coast and disposal site returned 25% and 20% respectively.

Release/return data are summarized in Tables 9 and 10. Straight-line vectors of current drift are shown in Figures 15 and 16.

Bottom Currents

Releases in May and October 1969 and August 1970 indicate a southwesterly movement of bottom water from the disposal site at an average speed of 0.3 nautical miles/day (range = 0.1-0.5). Spring releases were found at the mouth of Chesapeake Bay and the Cape Hatteras - Cape Lookout area of North Carolina. Recoveries from the fall releases were found further north along Assateague Island. A major change in bottom residual

TABLE 8

Station Positions for
Drift Bottle/Sea Bed Drifter Releases

Station	Position
A	38°44.2'N., 74°58.0'W.
B	38°41.5'N., 74°49.0'W.
C	38°39.2'N., 74°38.8'W.
D	38°38.0'N., 74°27.8'W.
2	38°38.5'N., 74°20.0'W.
4	38°32.5'N., 74°15.0'W.
5	38°32.5'N., 74°20.0'W.
6	38°26.5'N., 74°25.0'W.
8	38°26.5'N., 74°20.0'W.

TABLE 9

RESIDUAL BOTTOM CURRENT FROM SEA BED DRIFTERS

RELEASE				RETURN				
Station	Dist. from shore (n. miles)	Number Dropped	Number Returned	Position	Direction	Distance (n. miles)	Days	Miles/Day
Release of 15 May 1969:								
A	5	5	1	38°47'N., 75°05'W.	309	6	20	0.3
B	12	5	0	–	–	–	–	–
C	20	5	1	38°49'N., 75°12'W.	293	30	87	0.3
D	28	5	3	38°46'N., 75°05'W.	286	30	57	0.5
				36°53'N., 76°16'W.	193	251	575	0.4
				38°31'N., 75°03'W.	254	29	81	0.4
2	35	5	1	39°01'N., 74°56'W.	298	41	268	0.2
4	38	5	0	–	–	–	–	–
5	34	5	2	37°08'N., 75°51'W.	223	108	361	0.3
				37°08'N., 75°51'W.	221	108	361	0.3
6	30	5	2	37°23'N., 76°16'W.	218	137	645	0.2
				36°51'N., 75°58'W.	226	124	468	0.3
8	34	5	3	36°51'N., 75°58'W.	219	124	254	0.5
				35°15'N., 75°30'W.	196	298	262	0.6
				37°08'N., 75°51'W.	222	174	361	0.3
Release of 22 October 1969:								
5	34	4	2	37°59'N., 75°16'W.	223	55	510	0.1
				37°56'N., 75°18'W.	229	55	184	0.3
6	30	5	1	38°10'N., 75°09'W.	238	42	119	0.4
8	34	4	0	–	–	–	–	–
Release of 5 August 1970:								
5	34	6	1	36°50'N., 75°58'W.	217	130	422	0.3

TABLE 10

RESIDUAL SURFACE CURRENT FROM DRIFT BOTTLE RELEASES

RELEASE				RETURN				
Station	Dist. from shore (n. miles)	Number Dropped	Number Returned	Position	Direction	Distance (n. miles)	Days	*Miles/Day
Release of 15 May 1969:								
A	5	5	4	38°05'N., 74°34'W.	030	25	3	8.3
				37°55'N., 74°38'W.	010	11	4	2.7
				38°20'N., 74°28'W.	033	43	11	3.9
				38°35'N., 74°13'W.	034	62	22	2.8
C	20	5	2	38°21'N., 74°25'W.	014	44	11	4.0
				38°41'N., 74°28'W.	021	66	43	1.5
2	35	4	0	–	–	–	–	–
4	38	5	0	–	–	–	–	–
5	34	2	0	–	–	–	–	–
6	30	3	0	–	–	–	–	–
8	34	5	2	38°39'N., 74°09'W.	015	71	38	1.9
				38°58'N., 74°04'W.	009	94	69	1.4
Release of 22 October 1969:								
5	34	5	0	–	–	–	–	–
6	30	5	1	35°46'N., 75°32'W.	199	171	23	7.4
8	34	5	0	–	–	–	–	–
Release of 5 August 1970:								
2	35	5	0	–	–	–	–	–
5	34	5	0	–	–	–	–	–
8	34	3	0	–	–	–	–	–

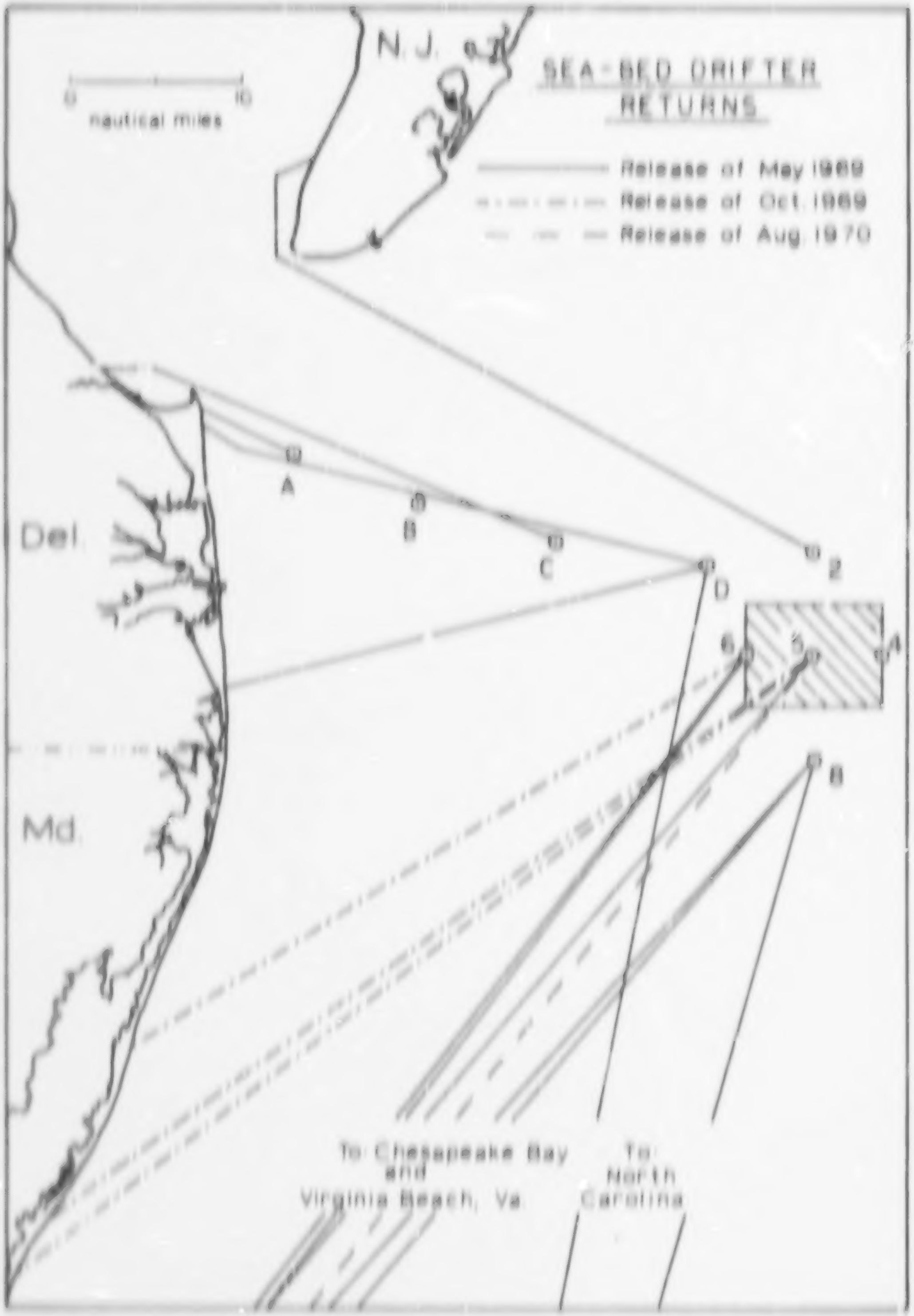

N.J.
SEA-BED DRIFTER RETURNS
0
10
nautical miles
Release of May 1969
Release of Oct. 1969
Release of Aug. 1970
Del.
Md.
A
B
C
D
2
4
5
6
8
To Chesapeake Bay and Virginia Beach, Va.
To North Carolina

FIGURE 15

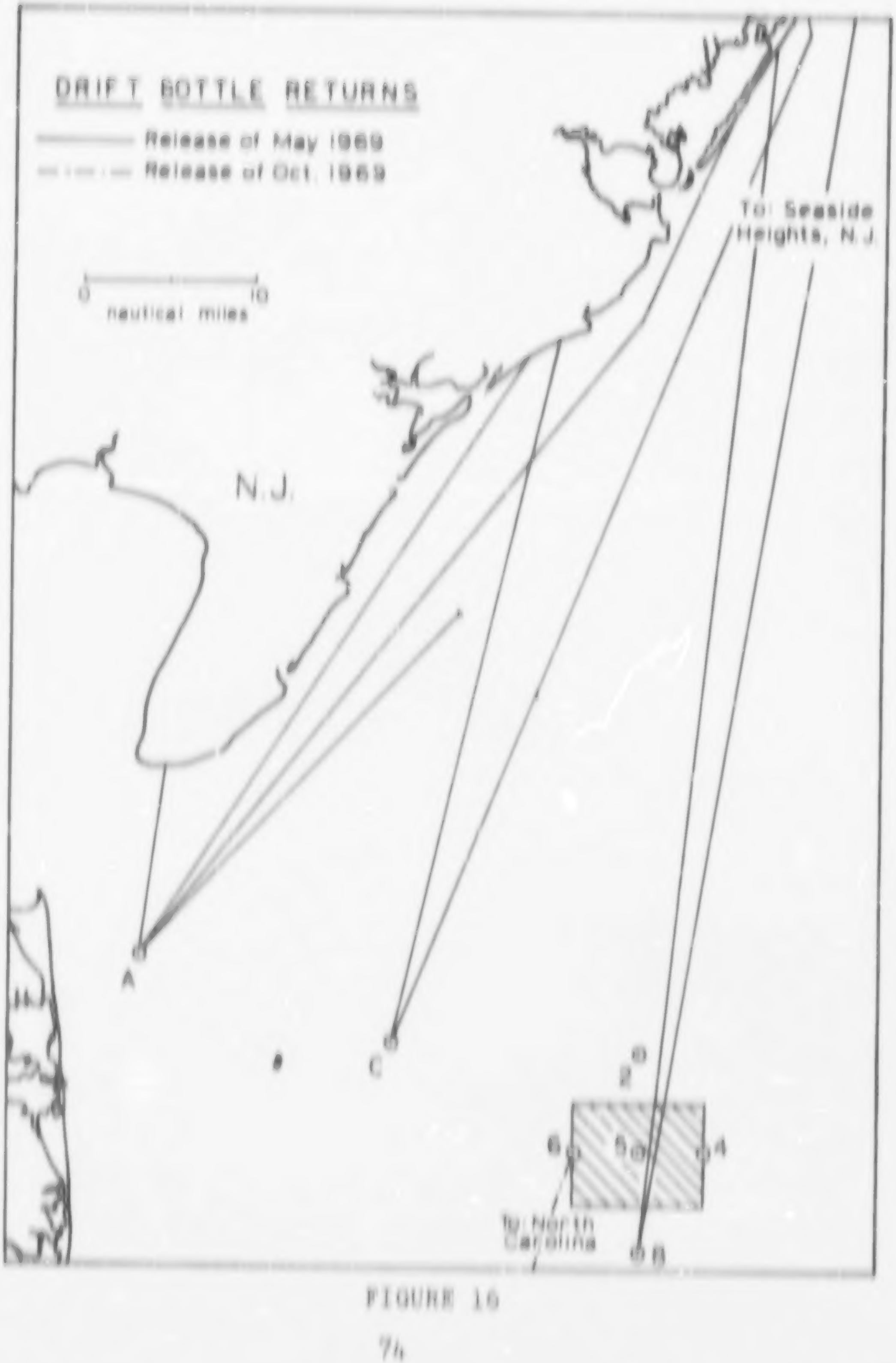

DRIFT BOTTLE RETURNS
Release of May 1969
Release of Oct. 1969
0
10
nautical miles
To: Seaside Heights, N.J.
N.J.
A
C
2
6
5
4
To North Carolina
B

FIGURE 16

current direction occurs in the vicinity of Station D and 2. Bottom water northwest of this point moved west-northwest toward the mouth of Delaware Bay, with two returns coming from inside the Bay. Water south and east of this point moved southwest. The breakover point appears to coincide with the approximate position of the 20-fathom (36.5 meter) isobath. The influence of Delaware Bay on bottom water movement appears then to be appreciable out to the northwestern corner of the disposal area.

Surface Currents

Surface currents are normally southwesterly in the disposal area[21]. The May, 1969, releases presented an anomalous picture as all recoveries showed a north to northeasterly trend with bottles stranding from Cape May to Seaside Heights, New Jersey. Drift speed averaged 1.6 nautical miles/day (range = 1.4-1.9) from the disposal site stations while stations closer to shore (A & C) averaged 3.9 nautical miles/day (range = 1.5-8.3).

In October 1969, the single return (Station 6) produced one of the fastest travel times found: 171 miles in 23 days or 7.4 per day. That bottle moved southwest to Oregon Inlet, North Carolina, as expected. Bumpus[22] suggests that anomalous reversals of surface drift may be more frequent than previously realised in the middle Atlantic Bight. He predicts that such reversals may occur at any time between April and September and are facilitated by low river runoff and winds from southerly quadrants. We would predict that there may be appreciable dispersion of the acid waste in a northerly direction during these reversals in late spring and summer since most of the iron is held above the thermocline and presumably follows, at least in part, the surface water drift. In the absence of reversals, the waste would be expected to move southwesterly.

SECTION V-C

PHYTOPLANKTON STUDIES

Phytoplankton samples were collected from surface waters at each station of the study area. Seventeen genera of diatoms, dinoflagellates and blue-green algae have been identified representing at least 20 species. The species composition of each sample is summarized in Tables B-6 to B-15 of Section VIII, Appendix B-2.

CRUISE SUMMARY

K-01-69 (15 May 1969)

Each station of this initial phytoplankton survey was completely dominated by dinoflagellates, especially *Ceratium tripos* and *C. longipes*. *Ceratium tripos* accounted for the larger percentage with the exception of Station 5 where *C. longipes* was more numerous. *Peridinium* sp. was the only other genus present in any numbers greater than 1% of the total sample.

K-02-69 (10 October 1969)

The diatoms, *Nitzschia seriata*, *Thalassiosira* sp., and *Biddulphia* sp. were the most abundant species in the area. At Station 5 *N. seriata* was dominant in numbers but it should be noted that its cell volume is one of the smallest of the species found in this study. Station 6 was dominated by

Thalassiosira sp., *Biddulphia* sp., and *Rhizosolenia alata*. There was a notable absence of *N. seriata*. At Station 8 *N. seriata*, *Thalassiosira* sp., and *R. alata* were abundant. Other species were few in number. Though dinoflagellates were present in only trace quantities, greater numbers of species were found in the genus *Ceratium* and *Peridinium* than in the May samples.

S-03-70 (1 June 1970)

The species composition of this survey was similar to that of the initial survey K-01-69 (15 May 1969). A distinction can be made in that *Ceratium tripos* dominated all four stations and *C. longipes* was not as abundant as in the initial survey. *C. fusus* was present in numbers comparable to those of *C. longipes*.

S-06-70 (6 July 1970)

The samples of this survey were again dominated by the dinoflagellate *C. tripos* with *C. longipes* of secondary importance at Stations 2 and 5. At Station 8 *C. tripos* constituted almost 100% of the sample. The only other genera comprising more than 1% at any station were *Dinophysis* sp. at Station 5 and *Peridinium* spp. at Stations 2 and 5.

K-04-70 (5 August 1970)

The volume of phytoplankton in the samples from this cruise was extremely low at all stations sampled. A blue-green alga (possibly *Trichodesmium* sp.) was present at all stations except Station 4. At Station 8 this was the only phytoplankton present. There was a greater number of species of the genus *Ceratium* than was found in the earlier summer samples.

8-09-70 (8 October 1970)

The samples in this survey were dominated by a filamentous blue-green alga, possibly *Trichodesmium* sp. It was found characteristically as bundles of filaments. The genus *Ceratium* was represenced by a large number of species which is similar to a situation similar to that found in the October samples of the previous year. It should be noted, however, that diatoms had not yet appeared.

8-10-70 (17 November 1970)

The samples from this survey had the greatest numbers of species of any survey. The percent composition showed, however, that the sample was dominated by the diatoms *Stephanopyxis turris* and *Rhizosolenia alata*. Other species were numerically much less significant.

B-01-71 (19 January 1971)

This sample was dominated by *Ceratium tripos*. The diatoms *Quindaria flaccida*, *Chaetoceros* sp., and *Biddulphia sinensis* comprised a great percent of the remaining sample. This is in contrast to summer samples where the dinoflagellates predominate while diatoms are few if present at all.

K-05-71 (19 March 1971)

The diatom *Quindaria flaccida* predominated at Stations 2, 5, 6, and 8 and *C. tripos* was dominant at Station 4. Of the remaining species only *Rhizosolenia alata*, *Chaetoceros* sp., and an unidentified arced chain form comprised more than 1% of the sample.

B-02-71 (27 May 1971)

The samples of this cruise, as in previous cruises at this time of year, were dominated by *C. tripos*. *C. longipes* was of secondary importance.

PHYTOPLANKTON FLORA

Dinoflagellates

Ceratium tripos occurred throughout the year. It was very abundant in the January, March, May, June, and July samples. It accounted for more than 50% of the cell count for the samples from January 1971, a single station in March 1971, four stations from May 1969, and all stations from May 1970, June 1970, July 1970, and June 1971. At other times of year it was present but not in large numbers.

C. longipes occurred from January to August. Its greatest concentrations were from May to July. In May 1969 it accounted for more than 50% of the phytoplankton at Station 5.

C. fusus occurred throughout the year but seldom in appreciable numbers. Its greatest abundance was in the months of May and June.

C. macroceros was present throughout the year but never in great numbers. Its highest concentration was in October 1970 where it comprised 10% of the sample from Station 5.

C. tripos f. lineatum was present in the spring, late summer, and fall. It never comprised more than 5% of a sample and usually was present in only trace numbers.

C. massiliense was a late summer-fall species. It was present in more than trace numbers only in October 1970.

C. carriense was represented only by a few specimens in October 1970.

C. extensum occurred in August and October 1970 but never was present in more than trace numbers.

Peridinium spp. were present throughout the year, represented by at least four species. Because of uncertainties in taxonomy it is presented here as *Peridinium* spp.

Two species of *Dinophysis* spp. were found during late spring and summer. One, provisionally designated as species *a*, was found from May until August. Species *b* was found only in May.

Prorocentrum sp. was found during late spring and summer but was never greater than 5% of a sample.

Diatoms

Biddulphia sinensis was present throughout the winter, (November to March) though never in large numbers.

Ditylum brightwelli occurred in October 1969 and November 1970 but only in trace amounts.

Guinardia flaccida was found from November 1970 to May 1971. In March 1971 it dominated four stations; only at Station 4 was it outnumbered by *Ceratium tripos*. At other times it was present in low numbers.

Lithodesmium undulata was present in November 1970 only in trace numbers.

Nitzschia seriata was present in October 1969 and November 1970. It was the dominant species at two of three stations in October 1969. In November 1970 it was present only in small numbers.

Rhizosolenia alata was of secondary importance in November 1970 and present only in small quantities in October 1969.

Stephanopyxis turris occurred only in November 1970. At this time it was the dominant species at all stations.

Stephanopyxis palmeriana occurred with *S. turris* but was present only in trace numbers at a single station.

Thalassionema nitzschiodes was present from November 1970 to March 1971, always in low numbers.

Blue-green Algae

A filamentous blue-green, identified as *Trichodesmium* sp., was present in the samples from August to November. This was the dominant species in the October 1970 samples. At other times it was present only in small quantities. *Trichodesmium* sp. has subsequently been found in this area in November[27].

Miscellaneous

Of the diatom genera identified, a few had representatives present from October or November to March or May. These included *Chaetoceros* spp., *Coscinodiscus* spp., and *Rhizosolenia* spp. Others, present only in October or November, were *Biddulphia* sp., *Pleurosigma* sp., and *Thalassiosira* sp.

In addition to photosynthetic algae and dinoflagellates, nonphotosynthetic planktonic forms such as foraminifera and radiolarians were occasionally found during the sampling program, but never in large numbers.

SEASONAL CYCLE

Table 11 summarizes the seasonal occurrence of phytoplankton in surface waters of the study area. These data indicate the presence of two major seasonal species associations, a spring-summer dinoflagellate-dominated regime, and a winter diatom-dominated regime. It is important to note that dinoflagellates were present throughout the year. Their summer dominance is due primarily to an almost complete lack of diatoms during June, July, and August. The presence of these species associations is correlated with water temperature and the presence or absence of the thermocline.

The dinoflagellate-dominated regime was found in surface waters from May until October, coincident with the presense of the thermocline. *Ceratium tripos* comprises the greatest percentage of the phytoplankton during this time, with highest numbers in May, June, and July. Of secondary importance during this time was *C. longipes* and *C. fusus*.

TABLE II

Seasonal Presence of Phytoplankton in the Waste Disposal Area

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
DINOFLAGELLATES												
Ceratium tripos	x	NO SAMPLES	x	NO SAMPLES	x	x	x	x	NO SAMPLES	x	x	NO SAMPLES
Ceratium fusus	x		x		x	x	x	x		x	x	
Ceratium macroceros	x		x		x	x	x	x		x	x	
Ceratium longipes	x		x		x	x	x	x		–	–	
Ceratium tripos f. lineatum	–		x		x	–	–	x		x	x	
C. massiliense	–		–		–	–	–	x		x	–	
C. carriense	–		–		–	–	–	–		x	–	
C. extensum	–		–		–	–	–	x		x	–	
Peridinium spp.	x		x		x	x	x	x		x	x	
Dinophysis sp. a	–		–		x	–	x	x		–	–	
Dinophysis sp. b	–		–		x	–	–	–		–	–	
Prorocentrum sp.	–		–		x	–	–	x		–	–	
DIATOMS												
Biddulphia sinensis	x		x		–	–	–	–		–	x	
Biddulphia sp.	–		–		–	–	–	–		x	–	
Chaetoceros spp.	x		x		x	–	–	–		x	x	
Coscinodiscus spp.	x		x		–	–	–	–		x	x	
Ditylum brightwellii	–		–		–	–	–	–		x	x	
Guinardia flaccida	x		x		x	–	–	–		–	x	
Lithodesmium undulatum	–		–		–	–	–	–		–	x	
Nitzschia seriata	–		–		–	–	–	–		x	x	
Pennate diatoms (unidentified)	–		x		–	–	–	–		x	x	
Pleurosigma sp.	–		–		–	–	–	–		–	x	
Rhizosolenia alata	–		x		–	–	–	–		x	x	
Rhizosolenia spp.	x		x		x	–	–	–		–	x	
Stephanopyxis turris	–		–		–	–	–	–		–	x	
Stephanopyxis palmeriana	–		–		–	–	–	–		–	x	
Thalassionema nitzschioides	x		x		–	–	–	–		–	x	
Thalassiosira sp.	–		–		–	–	–	–		x	x	

TABLE II (Cont'd.)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
OTHER FORMS												
Radiolarians	–	NO SAMPLES	–	NO SAMPLES	–	–	–	–	NO SAMPLES	x	x	NO SAMPLES
Foraminifera	x		x		–	–	x	–		x	–	
Blue-green filamentous: *(Trichodesmium* sp.)	–		–		–	–	–	x		x	–	
Unidentified spp.	x		x		–	x	x	–		x	–	

As the summer progressed, the number of species present increased, but volume of the collected samples decreased, reaching a minimum in August 1970. In late summer and early fall, bundles of filaments became very numerous in the samples. These were identified as the blue-green alga, *Trichodesmium*.

October and November were periods of transition in the phytoplankton community. Diatoms assume the greatest percentage of the samples and continued to overshadow dinoflagellates throughout the winter and early spring. *Nitzschia seriata* and *Thalassiosira* sp. dominated the October 1969 samples. In November 1970, *Stephanopyxis turris* and *Rhizosolenia alata* ranked 1 and 2 in abundance. This cruise produced the largest number of diatom species of any during the sampling period. *Guinardia flaccida* was present in small numbers in January 1971 and was the dominant diatom in March 1971. The dinoflagellate *Ceratium tripos* continued to be found throughout the winter and was the most abundant species in the single sample in January 1971. It was second in abundance in March 1971.

In summary, the dinoflagellate regime was dominated by a single species, *Ceratium tripos*, while the diatom regime was characterized by a number of different species reaching numerical dominance throughout the fall and winter. Plankton volumes were lowest in August, probably reflecting somewhat reduced amounts of available nutrients above the thermocline. Species numbers were highest in October-November, reflecting transition from dinoflagellate to diatom dominated floras.

The seasonal pattern described here is in general agreement with that found[24,25] in studies of shelf waters off the coast of Virginia. Those studies described a seasonal variation in *Ceratium* similar to that reported here including a May-June *C. tripos* maximum, a progressive increase in numbers of *Ceratium* species from early summer to a peak in the autumn months, high species diversity in the autumn, and a November bloom of *Stephanopyxis turris*. The species identified in our study as *C. longipes* is listed as *C. arcticum* by Mulford[24,25]. There is an intergradation between these two species and all are listed here as *C. longipes*. Mulford reported its presence in March and April for offshore waters of Virginia. In the Delaware area it appears to be at its greatest abundance in late May and early June.

Studies in Long Island Sound and the coastal waters of southern New England indicate the genus *Ceratium* is of much less significance, at least in near-shore waters[26-28]. A dinoflagellate-dominated summer population has been reported for Long Island Sound[29] but with a much different species composition than found in this study. Differences in species composition and seasonal occurrence of diatoms are also noted between the present study area and Long Island Sound and Southern New England. This can be mainly attributed to the fact that those studies were carried out in near-shore and estuarine waters.

PHYTOPLANKTON COEFFICIENT OF COMMUNITY

The Jaccard[30] coefficient of community index was employed in an effort to evaluate the degree of similarity between various station-pairs of a given cruise. The coefficient is defined by the formula:

$$C(N_1 + N_2 - C)^{-1}$$

where C is the number of species common to the two samples being compared and N is the number of species in each of the two samples. Values approaching 1.00 indicate maximum similarity whereas those approaching 0.00 indicate maximum dissimilarity. The index is based on presence or absence of species and is very sensitive to the occurrence of "rare" species. It does not, however, directly reflect differences in percent species composition between a pair of samples.

Data for the Jaccard coefficient are presented in Table 12. The arrangement of the stations was chosen to place station pairs with a high degree of similarity at the upper left and low similarity pairs at the lower right.

In most cases the coefficients were high and close together, indicating a high degree of similarity between stations for a given cruise. This is especially true for the early winter, spring, and early summer samples. Samples from mid-summer and fall (S-06-70, K-04-70, and K-02-69) showed a greater range of values. These are periods of increasing development of *Ceratium* species of low abundance (for which the index is very sensitive) and transition to the diatom regime of winter. The effect of patchiness on plankton

TABLE 12

COEFFICIENTS OF COMMUNITY: PHYTOPLANKTON

K-01-69
15 May 1969

Station	2	6	5	4	8
2		.857	.750	.857	.625
6			.625	.725	.714
5				.666	.857
4					.555
8					

K-02-69
11 Oct. 1969

Sta 5 + Sta 8	.600
Sta 6 + Sta 8	.437
Sta 5 + Sta 6	.333

S-03-70
1 June 1970

Station	4	5	2	8	6
4		1.000	.833	.800	.666
5			.833	.800	.666
2				.666	.571
8					.500
6					

TABLE 12 (Cont'd.)

S-06-70
8 July 1970

Sta 2 + Sta 5 .625

Sta 2 + Sta 8 .333

Sta 5 + Sta 8 .286

S-07-70
5-6 Aug. 1970

Station	2	5	4	6	8
2		.600	.400	.272	.250
5			.166	.272	.250
4				.182	.005
6					.100
8					

S-09-70
8 Oct. 1970

Sta 2 + Sta 5 .777

Sta 2 + Sta 8 .600

Sta 5 + Sta 8 .545

S-10-70
17 Nov. 1970

Sta 5 + Sta 8 .809

Sta 2 + Sta 5 .750

Sta 2 + Sta 8 .619

Table 12 (continued)

B-01-71
19 Jan. 1971

Sample From Station 8 Only

K-05-71
10 March 1971

Station	5	8	4	6	2
5		.933	.666	.733	.706
8			.533	.666	.647
4				.750	.600
6					.562
2					

B-02-71
27 May 1971

Station	5	2	6	4	8
5		.900	.900	.888	.727
2			.818	.800	.818
6				.800	.666
4					.800
8					

species distribution may be appreciable, but cannot be evaluated with any degree of certainty.

The coefficients support the finding at Stations 6 and 8 in August 1970 (K-04-70) that the phytoplankton population consisted almost entirely of the blue-green algae. The late summer period has been demonstrated to have low species diversity. Since the coefficient is very sensitive to the presence or absence of rare species, the low affinities are not surprising during this period of low phytoplankton abundance.

SECTION V-D

ZOOPLANKTON STUDIES

Zooplankton samples from the study area were usually dominated by calanoid copepods, both numerically and volumetrically. Copepods showed greater speciation than any of the other zooplankton group with a total of 32 species identified and four additional organisms identified to genus. Copepod dominance generally occurred throughout the year with greatest speciation in October and November. Collection data are summarized in Tables B-16 to B-24 of Section VIII, Appendix B-2.

The seasonal distribution of zooplankton (Table 13) shows greatest speciation in October and November coincident with high speciation in the phytoplankton and destruction of the thermocline. Much of the increase in species number during late summer is associated with an influx of warm water forms with southern affinities. In November, following thermocline destruction, colder water forms (e.g. *Tortanus discaudatus* and *Nannocalanus minor*) replace warm water forms. Lowest zooplankton species abundance was found in winter.

Highest plankton volumes occurred in the spring and early summer. Decreased volumes were found during the summer with a second increase in autumn. The spring and fall periods of high volume were associated with seasonal phytoplankton blooms and an influx of meroplanktonic larvae.

MAJOR ZOOPLANKTON GROUPS

Copepods

Centropages typicus was present throughout the year. There appeared to be two population maxima, one in May-July and a second from October to January. The greatest abundance was recorded at Station 2 in July. There was a relatively constant peak abundance from October to January. The adults were found primarily in the surface samples but the copepodites were distributed throughout the water column. Copepodites reached a maximum in July when they constituted a dominant portion of the samples. This species is a typical summer species in the Woods Hole area[31]. Its distribution is largely confined to the Mid-Atlantic Shelf region generally in the upper 10 meters of the water column[32]. It reaches peak abundance in the Inner Continental Shelf waters off lower Chesapeake Bay between November and May[33].

Paracalanus parvus was present in most months with maximum populations in July and October and an apparent winter minimum. There was no clear pattern to its vertical distribution. It is a cosmopolitan species, reported[34] throughout the year off the mouth of Delaware Bay where it had an early winter maximum.

Pseudocalanus minutus occurred throughout the year with its greatest abundance in June, November, and January. Its June maximum was the greatest for the year and the greatest for any other copepod species. Higher concentrations were at the surface but no clear evidence for population stratification was found.

It has been reported year-round off Delaware Bay[34] and off Chesapeake Bay[33] with a late summer minimum. Grice and Hart[35] report it to be one of the most frequently occurring species in coastal waters between New York and Bermuda.

Calanus finmarchicus occurred generally throughout the year confined primarily to the deep samples. It was not in the only surface zooplankton sample of the January cruise and its vertical distribution may account for this fact. It was never present in great numbers and there appeared to be a late summer minimum population. For the Continental Shelf Region from Cape Cod to Cape Fear it is reported to have an autumn and winter minimum and is generally confined to the lower layers[32].

TABLE 13

Seasonal Occurrence of Zooplankton in the Waste Disposal Area

SPECIES	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Copepods												
Anomalocera ornata	–	No Sample	No Sample	No Sample	x	x	–	–	No Sample	–	–	No Sample
A. patersonii	–				x	–	–	–		–	–	
Acartia sp.	–				x	–	–	–		–	x	
A. danae	–				–	–	–	–		x	–	
A. longiremis	–				x	x	x	–		–	–	
Calanus finmarchicus	–				x	x	x	x		x	x	
Calocalanus pavo	–				–	–	–	x		–	x	
Candacia armata	–				–	–	–	–		x	x	
C. pachydactyla	–				–	–	–	–		–	x	
Centropages bradyi	x				–	–	–	x		–	x	
C. furcatus	–				–	–	–	–		x	–	
C. hamatus	–				x	x	–	x		–	–	
C. typicus	x				x	x	x	x		x	x	
Copilia mirabilis	–				–	–	–	x		x	–	
Corycaeus spp.	x				–	–	–	x		x	x	
Eucalanus spp.	x				–	–	–	x		–	x	
Euchaeta marina	–				–	–	–	x		x	x	
Euterpina acutifrons	–				–	–	–	x		–	–	
Labidocera aestiva	–				–	–	–	–		x	–	
L. lobiancoi	–				x	–	–	–		–	–	
Macrosetella gracilis	–				–	–	–	–		–	x	
Metridia lucens	–				x	x	–	–		–	–	
Nannocalanus minor	x				–	–	–	–		–	x	
Oithona sp.	x				x	x	–	x		–	x	
Oithona similis	–				x	x	x	x		–	–	
Oncaea venusta	x				–	x	–	x		x	x	
Paracalanus parvus	x				x	x	x	x		x	–	
Pseudocalanus minutus	x				x	x	x	x		x	x	

Table 13 (continued)
Seasonal Occurrence

SPECIES	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Rhincalanus cornutus	–	No Sample	No Sample	No Sample	–	–	–	–	No Sample	–	x	No Sample
Sapphirina nigromaculata	–				–	–	–	–		x	x	
Scolecithrix danae	x				–	–	–	–		–	x	
Temora longicornis	–				x	x	x	x		x	–	
T. stylifera	–				–	–	–	x		x	x	
T. turbinata	–				x	–	–	x		x	x	
Tortanus discaudatus	–				x	–	–	–		x	–	
Undinula vulgaris	–				–	–	–	–		x	x	
copepodites	x				x	x	x	x		x	x	
harpacticoids	–				–	–	–	x		x	x	
Cladocera												
Evadne nordmanni	–				x	x	x	x		x	x	
E. spinifera	–				–	–	–	x		x	–	
Podon sp.	–				–	–	–	–		x	–	
Podon intermedis	x				–	–	–	–		–	–	
Podon leuckarti	–				–	x	–	x		–	x	
Penilia avirostris	–				–	–	–	x		–	x	
Protozoa												
Foraminifera	–				–	–	–	–		x	x	
Radiolaria	–				–	–	–	–		x	x	
Coelenterates												
Medusae	–				x	x	x	x		x	x	
Siphonophore	–				–	–	–	x		x	x	
Polyps	–				x	–	–	–		–	–	
Ctenophores	–				x	–	–	x		x	–	
Annelids												
Polychaetes	–				x	–	–	–		x	x	
Pteropods												
Carolina sp.	–				–	–	–	–		x	–	
Creseis virgula conica	–				–	–	–	–		x	–	
Creseis sp.	x				–	–	–	–		x	–	
Limacina retroversa	x				x	x	x	x		x	x	

Table 13 (continued)
Seasonal Occurrence

SPECIES	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Heteropods	-	No Sample	No Sample	No Sample	-	-	-	-	No Sample	x	x	No Sample
Ostracods	-				x	-	x	x		-	x	
Mysids	-				x	-	-	-		x	x	
Cumaceans	-				x	-	-	-		x	-	
Amphipods												
Benthic forms	-				x	-	x	-		x	x	
Hyperid	-				-	-	-	-		x	x	
Phronimid	-				-	-	-	-		-	x	
Decapods												
Lucifer faxoni	-				-	-	-	-		x	-	
Crangon septemspinosa	-				x	-	-	-		-	-	
Pagurids	-				-	x	x	-		-	-	
Urochordata												
Doliolum nationalis	-				-	-	-	x		-	-	
Thalia democratica	-				-	-	-	x		-	-	
Oikopleura sp.	-				x	x	x	x		x	x	
Doliolids	-				-	-	-	-		x	x	
Salps	-				-	-	-	x		x	x	
Chaetognaths												
Sagitta sp.	-				x	x	x	x		x	x	
Larval forms												
Ephyra larvae	-				-	-	-	-		-	x	
Anthozoan larvae	-				x	x	-	x		-	-	
polychaete larvae	-				x	x	-	-		-	-	
veligers	x				x	x	x	-		x	x	
Cyphonaute larvae	-				x	-	-	-		-	x	
crab zoea	-				x	x	x	x		x	x	
megalops	-				-	-	x	-		x	x	
shrimp zoea	-				x	x	-	x		-	-	
Thalassinidae larvae	-				-	-	-	-		x	x	
Pluteus larvae	-				-	x	-	x		x	x	

Table 13 (continued)
Seasonal Occurrence

SPECIES	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
bipinnaria larvae	-	No Sample	No Sample	No Sample	x	-	-	-	No Sample	x	x	No Sample
fish eggs	-				x	x	x	x		x	x	
fish larvae	-				x	x	x	x		x	x	
Unid. egg.	-				x	-	-	-		x	-	

Oithona similis was present in the spring and summer samples with a May population maximum. It appeared, in most cases, to be largely confined to the deep samples. It was reported year-round outside Delaware Bay[34] except in September. Though small, this species is of considerable importance in more northern waters and was one of three dominant species found by Grice and Hart[35].

Corycaeus spp. was present from August to January and more than a single species was present. Greatest concentrations occurred in October but it cannot be considered dominant at other times of the year. This genus has southern affinities and is generally considered a warm water form.

Minor Copepods

Spring-summer forms: There were a number of species found primarily during May, June, and July. Some were also present at other times of year but in reduced numbers. *Acartia longiremis* was found during this period though not in large numbers, as well as *Centropages hamatus*, *Metridia lucens*, and *Temora longicornis*. *Tortanus discaudatus* was found in May 1969 in significant numbers and in one October sample in trace numbers. None of these species were found consistently in large numbers and can be termed minor constituents.

Late summer-fall forms: A distinct group occurred from July to November. Many were warm water forms and, though there were many species, were seldom present in large numbers. Included are *Corycaeus* spp., *Oncaea venusta*, *Acartia danae*, *Calocalanus pavo*, *Candacia armata*, *C. pachydactyla*, *Centropages furcatus*, *Copilia mirabilis*, *Eucalanus* spp., *Euchaeta marina*, *Labidocera aestiva*, *Nannocalanus minor*, *Sapphirina nigromaculata*, *Scolecithrix danae*, *Temora stylifera*, *T. turbinata*, and *Undinula vulgaris*.

Additional copepod species were found in an examination of some of the phytoplankton tows. Seldom were there more than a few individuals of each and they represented extreme range extensions. Included are *Anomalocera ornata*, *A. patersoni*, and *Pontella lobiancoi*.

Cladocera

Five species represented the Cladocera. Though never dominating any of the quantitative samples, they were often present in large numbers. *Evadne nordmanni*, the most abundant organism in the May 1969 survey, occurred from May until November and was present in maximum numbers in May and August. *E. spinifera* was present from August to October and often occurred in similar abundance to that of *E. nordmanni*, when present. *Penilia avirostris* was present from August to November and in October was more abundant than *E. nordmanni*. *Podon leuckarti*, found in May, June, August, and November, was never abundant; its peak was in June. Another species, *P. intermedius*, was fairly common in the January surface sample. These species were reported outside Delaware Bay[34] with similar seasonal cycles.

Chaetognaths

The arrow worm, *Sagitta*, found throughout the year, was not tallied by individual species, although at least three species were present. They were often in the deep water samples during the day and at the surface during the night. Chaetognaths were least abundant during August.

Pteropoda

Species representing this group were present throughout the year, the most abundant being *Limacina retroversa*. *Creseis* and *Cavolina* were present but in very low numbers. *Limacina* migrated diurnally from the depths during the day to the surface at night. The largest population was at the surface in January. It has been reported as most abundant north of the mouth of Chesapeake Bay with peak abundance in May[32]. Distribution has been described as patchy.

Tunicata

The appendicularian, *Oikopleura*, and the doliolid, *Doliolum*, were the two major pelagic tunicates found. *Oikopleura* sp.

was present from May to November with greatest numbers in October. This summer and fall species has been tentatively identified as O. *dioica*. The seasonal occurrence of this species corresponds closely to that described for O. *dioica* by others[38].

Doliolids were present from August to November with maximum abundance in October. At least two species were found in the area. A related group, the salps, never occurred in more than trace quantities in the area. These two groups and *Oikopleura* are considered indicators of warm water.

Larvae of Benthic Invertebrates

Substantial numbers of meroplanktonic larvae occurred throughout the study. For the most part, they were present for only short periods of time but some groups were a major constituent of the plankton where they occurred. These included pluteus larvae, molluscan veligers, and crab zoea. Pluteus larvae were presrnt in May, June, August, and November with maximum numbers in November. Veligers were found from May to November although absent during the August survey. There was a high number of bivalve veligers and post veligers in November. A maximum of gastropod veligers occurred in May. There is the possibility that these veligers were of the pteropod, *Limacina*. Crab zoea were present in the period from May to October. The greatest occurrence was in late May and June. They appeared to exhibit a diurnal migration. Large numbers were found in the evening surface samples of the May, 1971, survey. Other larval forms made relatively minor contributions to the total amount of zooplankton.

CRUISE SUMMARIES

K-01-69 (15 May 1969)

Samples were taken at the surface and below the thermocline at five stations. Though samples were not quantitative (a broken flow meter), they showed some general trends, being dominated by copepods, cladocerans, *Sagitta*, *Limacina*, leptomedusae, and fish eggs. Surface samples taken during the day consisted of the cladoceran, *Evadne nordmanni*, the copepod, *Centropages typicus*, and leptomedusae. *Evadne* and the leptomedusae were especially prevalent at Stations 5 and 6. Fish eggs were also numerous in the surface samples. The deep samples taken during the day had greater concentrations of the copepod, *Calanus finmarchicus*, fish larvae and *Sagitta* sp.

K-02-69 (11 October 1969)

Of samples taken at Stations 5, 6, and 8, only three were quantitative due to a damaged flow meter. Generally, the groups of major abundance were the copepods, doliolids, and *Oikopleura*. Among the copepods, no species was dominant throughout the samples. The major species were *Centropages typicus*, *Oncaea venusta*, *Corycaeus* spp. and *Temora turbinata*. All were more or less equally distributed vertically. Though few in number, two species of copepods collected had definite southern affinities; *Sapphirina* and *Copilia*. Also present (Station 8, surface) were fragments of the alga, *Sargassum*.

S-03-70 (1 June 1970)

Clarke-Bumpus samples were taken at the surface and at depth at five stations. Lack of a flow meter reading at Station 2, deep, did not allow direct comparison of sample with others.

Generally, samples were of moderate volume in comparison to other sampling cruises. With some exceptions, the species compositions compared quite closely with those of the May, 1969, cruise. Copepods were dominant in all cases except Station 5 (deep) where *Sagitta* sp. greatly outnumbered all other species. The copepod, *Pseudocalanus minutus*, was present in exceedingly large numbers at Station 2 (surface). It appeared to show a reverse diurnal migration, more common at the surface during the day and in the deep samples at night. Another copepod, *Paracalanus parvus*, was quite prevalent in the deep samples of all stations. This was the second most numerous copepod, followed by *Centropages typicus* and *Calanus finmarchicus*. The copepod species list was similar to that of the May, 1969, cruise with the noted absence of *Tortanus discaudatus*.

The cladoceran, *Evadne nordmanni* and *Podon leuckarti*, were present, though in reduced numbers. *Evadne* was primarily at the surface and *Podon* below the thermocline. Other groups present in large numbers were the pteropod, *Limacina retroversa*, leptomedusae, and, at Station 2 surface, crab zoea. *Limacina* showed its greatest abundance in the deep samples below the thermocline. The leptomedusae were in greatest abundance at the surface and in large numbers at Station 4. Crab zoea of a single species were found primarily at Station 2 surface.

8-06-70 (8 July 1970)

Samples on this survey were of moderate volume compared to other surveys. The Station 2 (deep) sample was improperly preserved and was not sorted or counted. The remaining samples were dominated primarily by immature and adult copepods. Other organisms present in large numbers at some stations were *Sagitta* sp., *Limacina retroversa* and *Oikopleura* sp.

The copepods, *Centropages typicus*, *Pseudocalanus minutus*, *Paracalanus parvus*, and *Oithona similis*, were present in the greatest numbers. There was also a large number of immature copepods, almost totally *Centropages typicus*. This species was the dominant copepod in all the surface samples. If the copepodites of *C. typicus* are included, this species was the dominant organism in all samples taken. It appears from these samples that the copepodite stages of *C. typicus* are evenly distributed above and below the thermocline. The three species, *Pseudocalanus minutus*, *Paracalanus parvus*, and *Oithona similis* had a similar vertical distribution to that of the adult *C. typicus*, that is, they were abundant in the surface sample of Station 2 and abundant in the deep samples of Stations 5 and 8.

Of the other groups, the cladoceran, *Evadne nordmanni* and *Penilia avirostris*, were present in very small numbers. The tunicate, *Oikopleura* sp., was present in moderately large numbers at all stations. *Sagitta* sp. was relatively abundant in the deep sample from Station 5, as was the pteropod, *Limacina retroversa*.

K-05-70 (5 August 1970)

Samples were small in volume. Unfortunately, due to damage of the flowmeter, quantitative samples were secured only at two stations. Despite this lack of quantitative data, some general trends were noted. In general, there were a large number of species, some with southern affinities.

Five groups, the copepods, cladocerans, doliolids, salps, and *Oikopleura* dominated. The copepods *Centropages typicus*, *Paracalanus parvus*, *Oncaea* sp., and *Corycaeus* spp. were the most abundant of that group. The cladocerans, *Evadne nordmanni*, *E. spinifera* and *Penilia avirostris*, dominated the samples numerically. It is interesting to note that the two species of *Evadne* often were present in nearly equal numbers. Of the other groups, the doliolids were especially numerous, the salps, *Thalia democratica*, much less so. Also abundant was the appendicularian, *Oikopleura* sp.

B-09-70 (8 October 1970)

Samples were generally of moderate volume. The species composition was similar, in part, to other late summer samples. The presence of a thermocline indicated a relatively stable situation, typical of the summer and late summer. The groups present in greatest numerical abundance were the copepods, *Oikopleura*, and *Doliolum* with copepods present in greatest numbers. In this group, *Centropages typicus*, *Pseudocalanus minutus*, *Paracalanus parvus*, *Oncaea venusta*, and *Corycaeus* spp. were most numerous. *C. typicus* was in greatest concentrations in the surface samples of all stations and was dominant at Station 5. *P. minutus* was present in moderately large numbers in all samples. *P. parvus* was the dominant species in the surface sample of Station 2 but was not present at Stations 5 and 8. *O. venusta* was present in large numbers in the samples from Station 2 and in the surface sample from Station 5. *Corycaeus* was present in its greatest concentrations at the surface of Stations 2 and 8. Immature stages of copepods were relatively abundant in all samples.

Of the other groups, the cladocerans were present in relatively small numbers and absent altogether at Station 2. There were indications that Station 2 (deep) was from very near the bottom. This would account for the presence of normally benthic amphipods and polychaetes. There were few larval forms in the samples from this cruise. The greatest concentrations were of veligers at Station 8 (deep).

S-10-70 (17 November 1970)

Stations 2, 5, and 8 were sampled. The deep sample, Station 8, was improperly preserved and unsuitable for analysis. Generally, the samples were small in volume but had the greatest speciation of any cruise in this series. Many organisms were present in only scattered numbers. Groups with greatest abundance were the copepods, pteropods, *Sagitta*, bivalve veligers, and pluteus larvae. The most abundant copepods were *Centropages typicus*, *Calanus finmarchicus*, *Pseudocalanus minutus*, *Oncaea venusta*, *Corycaeus* spp. and *Oithona* sp., with larger numbers of copepodites. *P. minutus* was especially abundant at the surfaces of Stations 2 and 5. O. *venusta* was very numerous at Station 2 (surface).

Of the other groups *Sagitta* sp. was very abundant at Station 8 (surface). There were numerous bivalve veligers at all stations and a large number of pluteus larvae in the surface samples of Stations 5 and 8.

S-01-71 (19 January 1971)

Only one station was sampled because of severe working conditions. A relatively small volume surface Clarke-Bumpus sample was the only zooplankton secured. It was dominated primarily by copepods and *Limacina retroversa*. The dominant copepod was *Pseudocalanus minutus*. There were also large numbers of *Centropages typicus* and copepodites. Only one species of cladoceran, *Podon intermedius*, was present. The greater part of the volume of the same was accounted for by the pteropod, *Limacina retroversa*.

S-02-71 (27 May 1971)

Relatively small volume Clarke-Bumpus samples were taken at five stations (surface and depth). With some exceptions, the greatest abundance of zooplankton were in the deep samples from this survey. Generally, copepods were the most abundant group except for two samples. At Stations 4 and 6 deep gastropod veligers far outnumbered any other group or organism. The most abundant copepod was *Oithona similis*, followed by *Pseudocalanus minutus* and *Paracalanus parvus*. Of other forms, *Sagitta* sp. was the most abundant in most cases. The exceptions were at Station 2 (deep) and Station 5 (surface) where crab zoea were more numerous.

SECTION V-E

BENTHOS STUDIES

GENERAL DESCRIPTION OF BENTHIC BIOTA

The general character of the biota at all stations was very similar. All stations were dominated (by number) by the sand dollar, *Echinarachnius parma*; the sand shrimp, *Crangon septemspinosum*; and by a small ascidean, *Bostrichobranchus pilularis*. The arinaceous foraminifera, *Astrorhiza*, was also a dominant form at most stations. The dominant organism by biomass is the sand dollar, *E. Parma*.

Other common invertebrates were the sea stars, *Asterias forbesi* and *A. vulgaris*; a yellow sponge; heart clams, *Cardita borealis*; Mahogany clams, *Arctica islandica*; a clam drill, *Lunatia heros*; a small snail, *Solariella obscura*; an amphipod, *Unciola irrorata*; an isopod, *Edotea montosa*; the rock crab, *Cancer irroratus*; a shrimp, *Hippolyte* sp.; and a hermit crab, *Pagurus annulipes*. Common fish in the area included three species of hake: the silver hake, *Merluccius bilinearis*, the red hake, *Urophycis chuss*, and the spotted hake, *U. regius*; four species of flounder: the fourspot, *Paralichthys oblongus*, the winter, *Pseudopleuronectes americanus*, the windowpane, *Scophthalmus aquosus*, and the yellow tail, *Limanda ferruginea*; and two species of sea robin: the northern sea robin, *Prionotus carolinus*, and the striped sea robin, *P. evolans*. Detailed collection data is presented in Section VIII, Appendix B-2.

Only one invertebrate was not found after the start of the project, this being the sea mouse, *Aphrodita*. Eighteen sea mice were recovered in May of 1969 and 12 in October 1969. *Aphrodita* has again been found in the area in subsequent sampling. Very few large bivalves were found in this area as indicated in the clam dredge data (Tables 14 and 23). No live surf clams, either *Arctica islandica* or *Spisula solidissima*, were found in the center of the disposal site (Table 23).

TABLE 14

Clam Dredge Data
P-01-69
Pre-disposal Survey: May, 1969

Species	Station 3	Station 4	Station 5	Station 8
Porifera				
Yellow sponge	x	x	x	x
Echinoderms				
Ophiopholis aculeata	2			
Echinarachnius parma	1			
Echinarachnius parma (dead)	1			
Asterias sp.		2		50
Asteroidea		2		
Gastropoda				
Lunatia (*Polinices*) *heros*				1
Busycon caniculatum	1			
Decapoda				
Cancer irroratus (adult)	5	11	1	8
Fish				
Lophius americanus	1			
flounder - unidentified	1			1
skate egg cases	many			
Shell				
Spisula	66	98		80%
Placopecten (1 clapper)	20	21	5	5%
Arctica	7	21	many	15%
Busycon caniculatum	1			
fossil oyster			2	1

A marked seasonal change was not observed in the macrobenthos as many of these organisms have life cycles exceeding one year. Evidence of seasonal recruitment of young was apparent in the *Cancer* crabs where very large numbers of small crabs (1 cm. carapace width) were found in August 1970. Subsequent monitoring during the fall and winter verified the expected increase in size and decrease in numbers of this year class of crabs.

BINARY ANALYSIS OF STATIONS AND CRUISES

Tables 15-18 represent the result of applying a binary or presence-absence analysis to the data from the Otter Trawl and Small Biological Trawl (SBT) samples. Binary analysis weighs the presence or absence of all species equally. When a few species are common to all areas and make up a large majority of all organisms found in those areas, binary analysis can be particularly useful since it is sensitive to changes in the less common species. Jaccard's[30] coefficient of community, one of the most commonly used presence-absence coefficients[30], is used here.

The coefficient is defined by the formula $C(N_1 + N_2 - C)^{-1}$ where C is the number of species common to the two samples being compared and N is the number of species in each sample (1, 2) being compared. The value of the coefficient may vary from 1.0 to 0.0, higher values indicating greater similarity.

The coefficient for each pair of cruises and stations was calculated. These were then set up in a square table either in temporal or numerical order of cruises or stations respectively. The order on each table was then changed so that the cruise or station with the highest coefficients was on the top and left while the cruise or station with the lowest coefficients, i.e. the most different from all other stations or cruises, was on the bottom and the right.

OTTER TRAWL ANALYSES

The analysis by cruises (Table 15) of the Otter Trawl takes shows that station 8 is generally the most different. Stations 2 and 5 are usually alike and station 5 generally has the highest association with other stations. No station starts like the others and becomes progressively more unlike them.

The analysis by stations (Table 16) shows the data very scattered with few high similarities. Stations 6 and 8 show very low similarities between any cruises. Stations 2 and 5 show much irregularity and comparison of the cruises in each station shows little seasonality.

SMALL BIOLOGICAL TRAWL (SBT) ANALYSES

The analysis of the SBT data by cruises (Table 17) shows coefficients generally higher than those for the trawl data. This is probably due to the higher efficiency of the SBT. Stations 6 and 5 are again generally most like the other stations. On S-07-70 and K-05-71, 8 is the most different. Station 8 appears to be very like the other stations on the earliest cruises but becomes progressively different until K-05-71. It becomes more like stations 6 and 2 on S-03-71.

The analysis of the SBT data by stations (Table 18) shows stations 2 and 8 becoming more different through time, with higher similarity during cruises of the same season. Station 5 does not show this. Coefficient of community values for benthic organisms were found to be lower than those for planktonic organisms. This has been seen in data from other unimpacted marine areas and presumably reflects greater homogeneity of the planktonic compared to the benthic environment.

SEASONAL OCCURRENCE OF FISH

The analysis of the occurrence of fish (Table 19) shows that many species are present on a seasonal basis. Such fish are the silver hake, long-horned sculpin, and summer flounder.

Three species of bottom fish were found in the 1969 pre-disposed survey, but not 1970 or 1971; these were the fringe flounder, witch flounder, and toadfish. Two of the species were represented by a single individual and one by two individuals. Distribution records indicate that all three species are at the limits of their geographic range and are considered rare in this area or this far off-shore. No fish were found in 1971 that had not previously been found. Comparison of total fish species captured from year to year is different due to the different number of samples taken during the year. There was only one trawl cruise in 1969, five in 1970, and one in 1971. The presence of seasonal migrants is clearly seen in only the 1970 data. The

TABLE 15

COEFFICIENT OF COMMUNITY
BINARY ANALYSIS OF CRUISES
OTTER TRAWL

May 1970 (S-02-70)

Station	5	6	2	4	8
5	X	0.538	0.400	0.308	0.333
6		X	0.385	0.313	0.231
2			X	0.308	0.308
4				X	0.083
8					X

July 1970 (S-06-70)

Station	5	2	8
5	X	0.455	0.200
2		X	0.167
8			X

August 1970 (S-07-70)

Station	5	4	2	6	8
5	X	0.467	0.421	0.368	0.429
4		X	0.353	0.375	0.238
2			X	0.350	0.292
6				X	0.200
8					X

Table 15 (continued)

October 1970 (8-09-70)

Station	2	8
2	X	0.233
8		X

November 1970 (8-10-70)

Station	5	7	8
5	X	0.500	0.476
7		X	0.368
8			X

June 1971 (8-03-71)

Station	2	5	6
2	X	0.455	0.455
5		X	0.429
6			X

TABLE 16

COEFFICIENT OF COMMUNITY
BINARY ANALYSIS OF STATIONS
OTTER TRAWL

Station 2

	8-09-70	8-07-70	8-03-71	8-10-70	8-02-70	8-06-70
8-09-70	X	0.474	0.412	0.250	0.182	0.267
8-07-70		X	0.294	0.136	0.182	0.158
8-03-71			X	0.313	0.294	0.200
8-10-70				X	0.278	0.187
8-02-70					X	0.268
8-06-70						X

Station 5

	8-06-70	8-02-70	8-03-70	8-10-70	8-07-70
8-06-70	X	0.445	0.334	0.095	0.111
8-02-70		X	0.200	0.278	0.105
8-03-70			X	0.109	0.077
8-10-70				X	0.318
8-07-70					X

Table 16 (concluded)

Station 6

	8-02-70	8-07-70	8-03-71
8-02-70	X	0.143	0.143
8-07-70		X	0.125
8-03-71			X

Station 8

	8-09-70	8-07-70	8-10-70
8-09-70	X	0.278	0.190
8-07-70		X	0.111
8-10-70			X

Station 4

Insufficient sampling for comparison.

TABLE 17

COEFFICIENT OF COMMUNITY
BINARY ANALYSIS OF CRUISES
SMALL BIOLOGICAL TRAWL

August 1970 (8-07-70)

Station	6	5	2	4	8
6	X	.545	.524	.529	.517
5		X	.500	.444	.400
2			X	.562	.400
4				X	.562
8					X

October 1970 (8-09-70)

Station	8	5	2
8	X	.341	.265
5		X	.261
2			X

March 1971 (K-01-71)

Station	6	5	2	4	8
6	X	.417	.419	.394	.296
5		X	.375	.267	.243
2			X	.316	.219
4				X	.242
8					X

June 1971 (8-03-71)

Station	2	8	6
2	X	.474	.433
8		X	.406
6			X

TABLE 18

COEFFICIENT OF COMMUNITY
BINARY ANALYSIS OF STATIONS
SMALL BIOLOGICAL TRAWL

Station 2

	8-07-70	8-09-70	E-01-71
8-07-70	X	0.428	0.393
8-09-70		X	0.233
E-01-71			X

Station 4

	8-07-70	E-01-71
8-07-70	X	0.286
E-01-71		X

Station 5

	8-07-70	E-01-71	8-03-71	8-09-70
8-07-70	X	0.400	0.364	0.384
E-01-71		X	0.487	0.271
8-03-71			X	0.273
8-09-70				X

Table 18 (concluded)

Station 6

	5-07-70	5-03-71
5-07-70	X	0.606
5-03-71		X

Station 8

	5-07-70	5-09-70	5-03-71	6-01-71
5-07-70	X	0.516	0.366	0.355
5-09-70		X	0.400	0.200
5-03-71			X	0.257
6-01-71				X

TABLE 19

Seasonal Occurrence - Fish
All Stations - Otter Trawls

	May	June	July	August	September	October	November
FLOUNDER (Pleuronectiformes)							
Citharichthys arctifrons Gulf Stream Flounder				70			
Glytocephalus cynoglossus Witch Flounder	69						
Limanda ferruginea Yellow-Tail Flounder	69 70						70
Pseudopleuronectes americanus Winter Flounder	69 70	71		70		70	70
Paralichthys dentatus Summer Flounder						70	
Paralichthys oblongatus 4-Spot Flounder	69 70	71					70
Scopthalmus aquosa Window-Pane Flounder	69						70
Etropus crossotus Fringe Flounder	69						
Flounder-juvenile			70			70	
HAKE (Gadidae)							
Merluccius bilinearis Silver Hake	69 70	71	70	70			
Urophycis chuss Red Hake	69 70		70	70			
Urophycis regius Spotted Hake		71		70		70	

Table 19 (continued)

	May	June	July	August	September	October	November
RAYS (Rajiidae)							
Raja eglanteria Clear-Nosed Skate							70
Raja erinacea Little Skate	69 70		70	70			70
Skate Egg Cases	69			70		70	70
SEA ROBINS (Triglidae)							
Prionotus carolinus Northern Sea Robin	60 70	71					70
Prionotus evolans Striped Sea Robin						70	70
SCULPINS (Cottidae)							
Hemipterus americanus Sea Raven	69			70		70	
Myoxocephalus octo-decemspinosis Long-Horned Sculpin	69 70			70			
OTHERS							
Lepophidium cervinum Fawn cusk-eel						70	
Lophius americanus Goosefish	69 70			70			70
Macrozoarces americanus Ocean Pout	69 70						

Table 19 (concluded)

	May	June	July	August	September	October	November
Opsanus tau Oyster Toad Fish	69						
Stenotomus chrysops Scup		71					70
Angel Fish (Chaetodontidae)			70				
Fish-unidentified			70				
Finfish-juvenile						70	

trawl size was reduced from 30 ft to 15 ft in early 1970 because of the capability of the vessel. This decreased the efficiency of the trawling effort.

Table 20 shows the relative geographic position of each station and the total number of fish species taken at each station. This shows a general pattern of fewer species of fish taken in the predominantly downstream direction. Stations 4 and 6 were sampled less frequently than the other stations and their values may be somewhat low.

DEAD/LIVE SAND DOLLAR RATIOS

The percentage of dead sand dollars in SBT samples was measured commencing with cruise S-07-70 (August 1970). Sand dollars live on or just below the surface of the sand and their tests (shells) are not likely to be carried away by currents after death. The tests presumably dissolve slowly so that a higher percentage will result when they are dying at an unusual rate. Sand dollars were counted as "dead" if only the test remained or if the animal had deteriorated to the extent that some of the white test was easily visible. Stations showing high percentages generally showed many dollars with blackened bodies and deteriorated skin and spines.

Data on percentage of dead *E. parma* are summarized in Table 21. Figure 17 shows the seasonal change in this percentage at stations 5 and 8. There is a suggestion that higher mortality may occur during the winter months (November-March). This coincides with the peri[illegible] homogenous water and rapid penetration of waste to the sea floor. It is conceivable that this winter mortality of *E. parma* may be a normal occurrence, perhaps as a consequence of autumnal spawning. However, the samples from March 1971 (K-05-71) do not support this as the percentage of dead sand dollars is much less at stations 2 and 5 than at stations 4, 6, and 8. We would expect a greater uniformity of results among the stations if this were entirely due to "natural" causes. Resolution of these data awaits additional information on the basic biology of *E. parma* in this area.

Samples from June 1971 show no dead tests in areas which had high percentages in the previous March cruise (stations 6 and 8). This suggests that tests may be broken up more rapidly than expected.

TABLE 20

NUMBER OF FISH SPECIES TAKEN ON ALL CRUISES

Station	2
Species	22

Station	6	5	4
Species	10	21	16

Station	8
Species	15

TABLE 21

E. parma, % dead (from BBT trawls)

Cruise 8-07-70
August 1970

Station 2

N = 765; 763 live, 2 dead
(0.26% dead)

Station 6

N = 89; 87 live, 3 dead
(3.37% dead)

Station 5

N = 540; 466 live, 74 dead
(13.70% dead)

Station 4

N = 379; 352 live, 27 dead
(7.12% dead)

Station 8

N = 702; 697 live, 5 dead
(0.71% dead)

Cruise 8-09-70
8 October 1970

Station 2

N = 99; 89 live, 10 dead
(10.10% dead)

Station 5

N = 337; 282 live, 55 dead
(16.32% dead)

Station 8

N = 333; 324 live, 9 dead
(2.70% dead)

Cruise 8-10-70
17 November 1970

Station 2

N = 223; 213 live, 10 dead
(4.48% dead)

Station 5

N = 81; 56 live, 25 dead
(30.86% dead)

Station 8

Insufficient sample for analysis

Table 21 (continued)

Cruise R-01-71
10 March 1971

Station 2

N = 526; 516 alive, 10 dead
(1.90% dead)

Station 6

N = 262; 136 alive, 126 dead
(48.09% dead)

Station 3

N = 435; 412 alive, 23 dead
(5.29% dead)

Station 4

N = 38; 28 alive, 10 dead
(26.32% dead)

Station 8

N = 91; 71 alive, 20 dead
(21.98% dead)

Cruise R-03-71
1 June 1971

Station 2

Trawl malfunctioned

Station 6

N = 232; 232 alive, 0 dead
(0.00% dead)

Station 3

N = 586; 582 alive, 4 dead
(0.68% dead)

Station 8

N = 175; 174 alive, 0 dead
(0.00% dead)

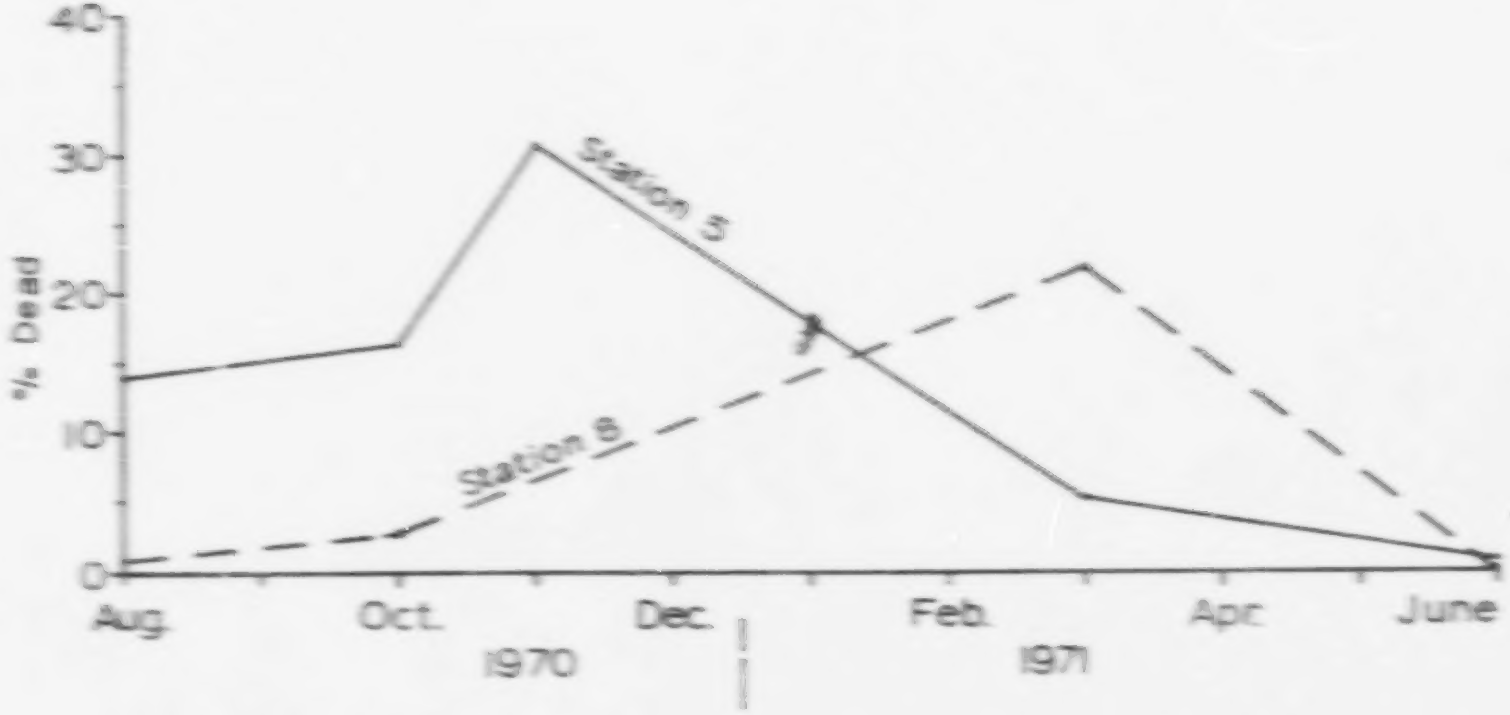


Figure 17 . % Dead Sand Dollars (*E. parma*) taken with the Small Biological Trawl.

SECTION V-F

UNDERWATER TELEVISION AND PHOTOGRAPHS

Visual representation of the sea floor was obtained with underwater television in the pre-disposal survey (May, 1969) and with 35 mm black and white photographs in July, 1970.

Many of the larger benthic and epibenthic organisms could be identified in both television and photographs, including crabs (*Cancer*), sea stars (*Asterias*), sand dollars (*Echinarachnius*), and erect sponges. Skates and bottom fishes such as flounder and hake could also be recognised. Tracks, trails, and burrows were almost absent as expected in sand bottoms with relatively high current velocities. One feature which could be studied was the abundance and distribution of shell upon the surface of the sea floor.

A striking feature of the pre-disposal survey (May, 1969) were the great amounts of pelecypod shell litter on the bottom within the disposal area. Estimates of shell type from television images agreed closely with counts made from Outer Trawl and surface clam dredge hauls (Table 22). The surf clam, *Spisula solidissima*, constituted 70-100% of the shell litter at all stations except 5 where the mahogony clam, *Arctica islandica* dominated the dredge hauls. Television showed *Arctica* at Station 5 to be clumped into shell heaps or windrows. Three such accumulations were seen at this station. The striking feature is that this same pelecypod fauna is not present as living clams under these areas. Data from the hydraulic clam dredge showed virtually all living clams in the area to be *Arctica islandica* (Table 23). No living clams were obtained from Station 5. This finding suggests that the great amount of predominantly *Spisula* shell litter was probably transported into the area from elsewhere, probably the commercial *Spisula* beds to the north.

Analysis of bottom photographs confirms the television observations of bottom organisms and shell litter. Photographs were taken only at Stations 2, 5, and 8. Benthic life, or evidence of it was seen in 75-85% of the photographs from each station with sand dollars, sea stars, and crabs being common (Table 24). There were, however, notable differences in kinds of life between the stations. Sand dollars were very abundant at Stations 2 and 8, but almost non-existent in the pictures from the center of the disposal area. Sea stars (*Asterias*) were clearly the dominant organism at Station 5. A curious mound-like structure was frequently seen at Stations 2 and 5. The organism responsible has not been identified. Other organisms seen in the photographs include crabs (*Cancer*), fish (mostly hake), sponge, bryozoa, and worm tubes.

The bottom was quite flat without ripple marks. A litter of pelecypod shells was found, in varying amounts, at all stations. Station 2 had low shell litter with most of it in the form of fragments. Stations 5 and 8 had a high percentage of whole shells. Station 5 had the highest amount of shell litter, but it was patchy in arrangement. This station was dominated by the mahogany clam, *Arctica islandica*. The surf clam, *Spisula solidissima*, was the dominant shell type at Station 8 (Figures 18 and 19).

Table 22 Pelecypod shell types on sea floor by %. (Predisposal Survey - May 1969)

Station	Gear Code	Spisula	Arctica	Scallop (Placopecten)	Razor Clam	Fossil Oyster	Volume of Sample
2	1	70%	7%	22%	1%		1 3/4 gal. (n=95)
	3	95%	5%				
4	1	70%	15% (21)	15%			1 gal.
	2	80%	10%	10%		less than 1%	
5	1	2%	96%			2%	2 1/4 gal.
	2	10%	90%				
	3	50%	50%(1)				
6	3	100%					Almost no shell seen
8	1	80%	15%	5%		less than 1%	1 1/2 gal.
	2	100%					
	3	90%	10%			less than 1%	

Gear Code: 1 = Clam Dredge; 2 = Otter Trawl; 3 = TT
(1) Windrows of shell are almost exclusively *Arctica*.

Table 23 Live clams taken with the hydraulic dredge. June 1969 (A-01-69)

STATION	DEPTH	*Arctica islandica*	*Spisula solidissima*	OTHER
2 (Note 1)	37.05m.	301	3 live ones, 2 of which were broken	
4	44.95m.	187	none	4 *Modiolus*
5	43.15m.	none	none	
8	37.8m.	19	none	Many sand dollars

Note 1: A single live *Arctica* (75 mm) was taken in the otter trawl at this station.

Table 24 Bottom Photo Analysis

Cruise E-18A-70 17-18 July 1970

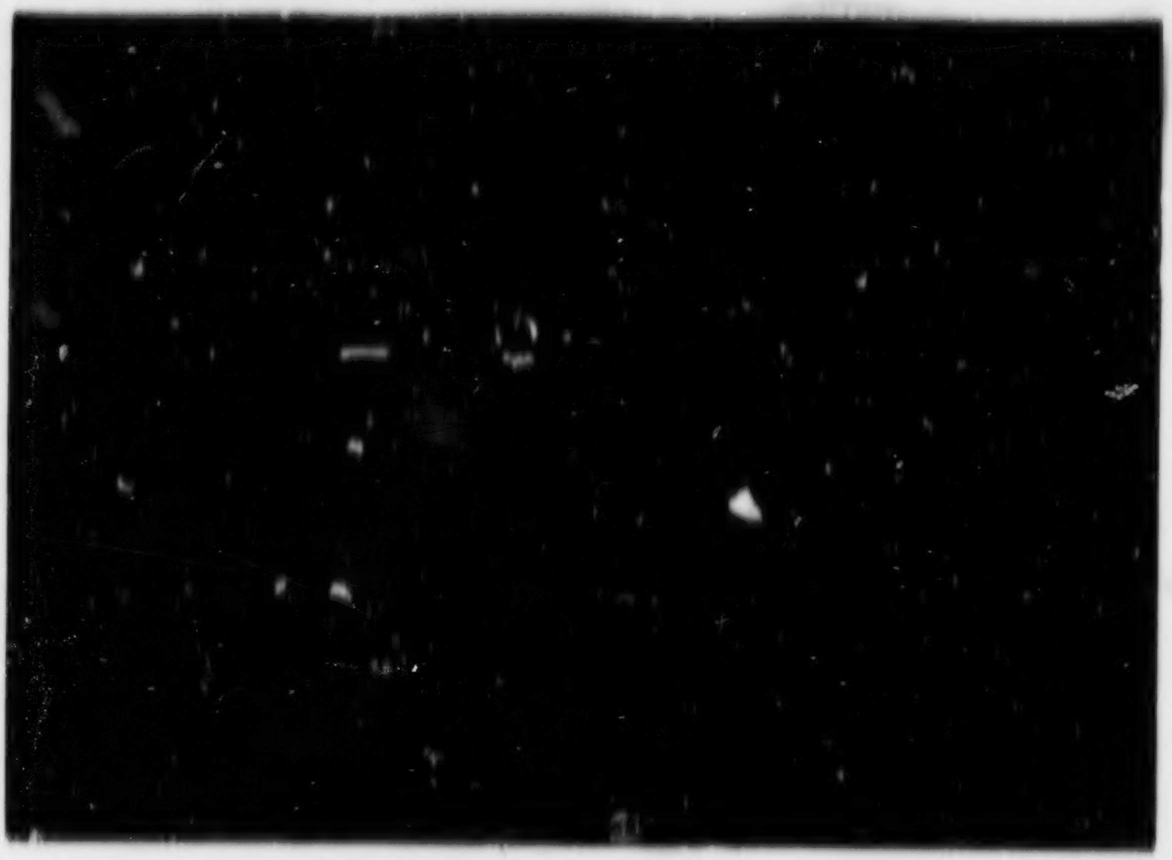
	Station 2	Station 5	Station 8
No. of frames	18	26	20
No. of frames with life	14	20	17
% with life	78%	77%	85%
Kinds of life (no. frames)			
Sand Dollar	9	1	7
Sea Star	1	10	8
Cancer	2	1	3
Sponge	1	1	-
Fish	3	3	2
Worms/Bryozoa/Hydroids	1	3	2
"Mounds"	4	5	-
Shell Litter			
Absent-Light	11	8	16
Moderate	5	7	2
Heavy	2	11	2
Dominant Shell Type	Fragments	*Arctica*	*Spisula*

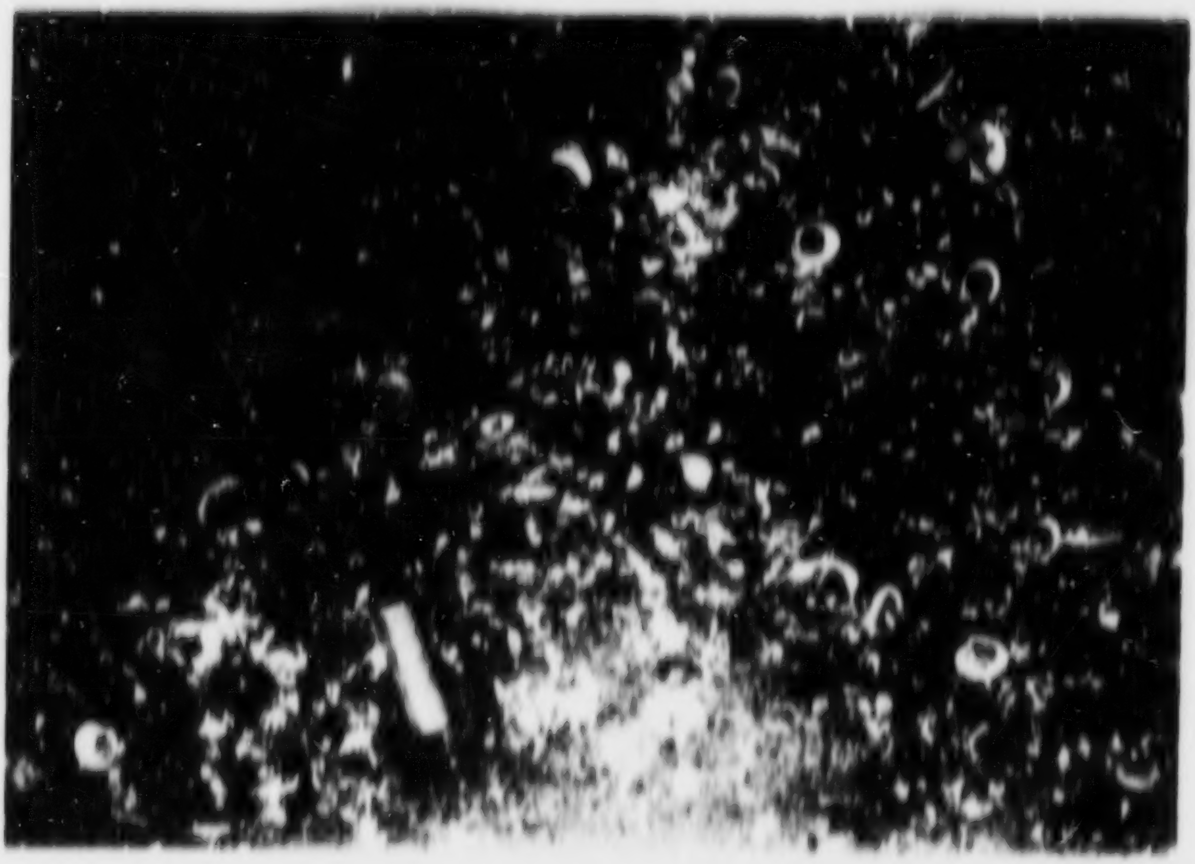
Figure 18. Bottom Photograph, Station 8, Low Amount of Shell Litter.

This photograph shows a high concentration of sand dollars and very little amount of shell litter. The object in the upper left is the trigger weight which fires the camera strobe. The area in the photograph is approximately 1.5 meters wide. (Photograph, Station 8, Strip A1 (3), Frame 22)

Figure 19. Bottom Photograph, Station 8, Heavy Accumulation of Shell Litter.

Note the heavy accumulation of shell (*Arctica*, *Spisula*, *Placopecten* and *Ensis*) and the large crab (*Cancer*) at the left edge of the photograph. The area in the photograph is approximately 1.5 meters wide. (Photograph, Station 8, Strip A1 (1), Frame 28)





SECTION V-G

SEDIMENT ANALYSIS

MECHANICAL ANALYSIS

Sediments were obtained from the study area in October 1969 and May, July and August 1970. This repetition sampling provided information on the variability of sediments at a given sampling station. A cumulative sediment size curve (based on cumulative weight per cent) was prepared for each sample. Data points were picked from these curves to prepare the statistical parameters of graphic mean (M_z), inclusive graphic standard deviation (σ_I), inclusive graphic skewness (Sk_I), and graphic kurtosis (K_G) for each sample. Results of these calculations are presented in Table 25. Table 26 presents these data in descriptive format. The method of calculation for each statistic and the descriptive nomenclature of M_z are shown in Tables B-44 and B-45 of Section VIII, Appendix B-3.

Bottom sediments in the waste disposal area were found to be fine to coarse sands, usually moderately well sorted, and with cumulative sediment distribution curves skewed toward coarse fractions. Mean particle size in the sample series varied from 0.21 to 0.59 mm. No samples were found with appreciable quantities of gravel or silts.

Replicate samples from stations 2, 4, and 5 showed good agreement for each station. Replicates from stations 6 and 8 were less similar and may reflect differences in closely adjacent sample areas, or differences due to minor navigation errors. Sediments at station 4 contained large numbers of living astrohrizid foraminifera which account for the comparatively coarse nature of the sediments in that area.

Sediment pH ranged from 7.1 to 7.5 in sediments sampled during 1970 cruises. Near bottom water samples showed values from 7.3 to 8.1 at corresponding stations.

TABLE 25

Statistical Analysis of Grain Size Distribution Data (Ø units) for M_z and σ_I

Statistical	Station 2	Station 4	Station 5	Station 6 (2 Samples)		Station 8
S-02-69 Oct. 1969						
M_z			1.53	1.02	1.10	
σ_I			0.44	0.67	0.61	
Sk_I			0.23	-0.11	-0.25	
K_G			1.14	+1.04	+0.97	
S-02-70 Mar 1970						
M_z	1.33	0.98	2.32	2.30		2.25
σ_I	0.62	1.04	0.72	0.79		0.46
Sk_I	-0.76	-0.65	-0.17	0.01		0.10
K_G	1.06	[illegible]	1.99	1.78		1.21
S-06-70 July 1970						
M_z	1.73		2.29			0.88
σ_I	0.75		0.62			0.67
Sk_I	-0.17		0.07			-0.13
K_G	1.29		1.15			0.90
S-07-70 Aug. 1970						
M_z	1.46	0.79	1.32	0.75		1.42
σ_I	0.47	0.57	0.62	1.47		0.61
Sk_I	-0.01	-0.41	-0.22	-0.43		-0.32
K_G	1.74	1.24	1.12	1.23		1.11

TABLE 26

Description of Bottom Sediments

Cruise	Station 2	Station 4	Station 5	Station 6	Station 8
S-02-69 (Oct. 1969)			medium sand, well sorted, fine skewed, leptokurtic	medium sand, moderately well sorted, coarse skewed, mesokurtic	
S-02-70 (May 1970)	medium sand, moderately well sorted, coarse skewed, mesokurtic	coarse sand, poorly sorted, strongly coarse skewed, leptokurtic	fine sand, moderately sorted, fine skewed, very leptokurtic	fine sand, moderately sorted, symmetrical, very leptokurtic	fine sand, well sorted, near-symmetrical, leptokurtic
S-06-70	medium sand, moderately sorted, coarse skewed, leptokurtic		fine sand, moderately well sorted, symmetrical, leptokurtic		coarse sand, moderately sorted, coarse skewed mesokurtic
S-07-70 (Aug. 1970)	medium sand, well sorted, symmetrical, very leptokurtic	coarse sand, moderately sorted, strongly coarse skewed, leptokurtic	medium sand, moderately well sorted, coarse skewed, mesokurtic	coarse sand, poorly sorted, strongly coarse skewed, mesokurtic	medium sand, moderately well sorted, coarse skewed, mesokurtic

SEDIMENT IRON

Sediment from the August 1970 cruise (8-07-70) was analyzed for iron. A standard ore analysis for Fe_2O_3 was employed, using hot HCl and NH_4OH for dissolution and precipitation of the iron. Duplicate samples were taken from each Peterson grab sample. Results of these analyses are shown in Table 27.

TABLE 27

SEDIMENT IRON

Cruise 8-07-70 5 August 1970

Station No.	Range (2 samples) (mg/gm)	Mean (mg/gm)
2	8.4 - 5.5	7.1
4	4.3 - 3.5	3.9
5	9.6 - 6.6	8.1
6	7.1 - 6.8	6.9
8	5.3 - 4.2	4.8

Stations 2, 5 and 6 had similar mean values in the 6.9 to 8.1 mg/gm range whereas stations 4 and 8 were distinctly lower with means of 3.9 and 4.8 mg/gm respectively. Station 5 had the highest mean value (8.1 mg/gm). These values are near the general range of sediment iron values (5.3-7.5 mg/gm) reported from New York Bight by Redfield and Walford[7].

If iron is precipitating onto the bottom in appreciable quantity, greatest concentrations would be expected on the surface of the sediments. The Peterson grab brings up material from the upper 12-15 cm. of the bottom, hence, the absence of good replication in some of the sample duplicates may be due to sediment-depth related concentration differences.

It is important to note that iron in the sediments is probably not uniformly distributed among the sediment size fractions. To test this, a third sediment sample was obtained from station 5 in August 1970. Half of this sample was analyzed for iron and produced 4.19 mg/gm. The second half was separated into coarse and fine fractions with a 250 micron sieve (phi = 2.0). Table 28 shows that iron concentrations were approximately 4 times higher in the fine fraction than in the coarse fraction, but the fine fraction made up only 19% of the total sample by weight.

TABLE 28

SEDIMENT IRON IN COARSE AND FINE SIZE FRACTIONS

Cruise 8-07-70 5 Aug. 1970 Station 5

	Fine Fraction (<250 microns)	Coarse Fraction (>250 microns)
% Sample by Weight	19.03	80.97
mg Fe/gm of Fraction	10.26	2.76
mg Fe/gm of Total Sample	1.95	2.35
mg Fe/gm total sample (by total sample analysis)		4.19
mg Fe/gm total sample (by addition of fraction analyses)		4.30

SECTION V-K

WASTE TOLERANCE STUDIES

A preliminary experiment was undertaken to determine the tolerance of a representative benthic organism, the northern sand dollar, *Echinarachnius parma*, to various concentrations of iron-acid waste. [illegible] *parma* is present throughout the disposal area, is slow moving, and lives immediately below the sediment-water interface.

Experimental animals were obtained on 2 July 1971 in 25 meters of water at 38°43.3'N., 74°41.5'W., a position 20 nautical miles from the designated center of the disposal grounds and 15 nautical miles from the nearest disposal point. Specimens from this area were bright reddish-pink in color in contrast to the dark red-brown color of the specimens collected from the disposal area. As no information was discovered on natural color variation in *E. parma*, the significance of the difference is uncertain. Bottom water at the collection site was 8.6°C and had a salinity of 30.8°/oo.

The specimens of *E. parma* were taken to the laboratory in insulated boxes containing sediment and bottom water from the collection location. They were held in the laboratory in a large recirculating aquarium at 10°C, 30°/oo for 10 days before beginning tolerance studies.

Healthy looking *E. parma* were selected from the holding tank and divided into 8 groups of 6 animals each. The diameter of the animals ranged from 27-48 mm, with a mean of 38.2 mm. Each group of 6 animals was placed in a 6-quart rectangular aquarium containing 4 liters of filtered sea water taken from the collection location. Each aquarium was held at 7°C and aerated with an air stone. No sediment or food was provided in the experimental tanks and water was not changed. Animals were examined approximately once each day. Mortality was considered to have occurred when no spine or podial movement could be observed under microscopic examination.

After two days of acclimation to the experimental tanks, acid waste was added to six of the tanks. The waste was from Iron D-60, collected 13 October 1970. Composition of the waste according to analysis by Du Pont at the time of collection was: total iron, 42.06 mg/liter; acidity, 16.51% (as H_2SO_4); specific gravity, 1.182.

At the time of the experiment, an additional analysis of the waste by another laboratory indicated the following partial elemental analysis:

Element	mg/liter
Cu	0.34
Fe	47,100
Mg	194
Ti	1,500
Al	61.2
Mn	1,400
V	106
Cr	110
Na	214
Ca	26.2
Zn	0.14

The eight experimental tanks received concentrated waste in the following amounts:

Tank No.	Waste Added	Waste Concentration	Calculated Amount Fe Added (mg/l)
I	none	Control I	none
II	none	Control II	none
III	0.4 ml	1:10,000	4.7
IV	0.8 ml	1: 5,000	9.4
V	1.6 ml	1: 2,500	18.8
VI	2.4 ml	1: 1,667	28.3
VII	3.2 ml	1: 1,250	37.7
VIII	4.0 ml	1: 1,000	47.1

The tanks were examined between the 3rd and 5th hours after waste addition. Tanks III-IV contained yellow colored water and tanks VII and VIII had yellow-brown flocculent precipitate present on the bottom with clear water above it. The yellow material was presumably precipitating iron. The pH was depressed in proportion to the amount of waste added, and in most cases, made a recovery of 35-60% during the first 24 hours after acid addition (Figure 20). At the termination of the experiment (270-300 hours), the pH in all tanks has risen to at least 7.25.

Figure 21 shows survival of *E. parma*. With the exception of the 1:1,000 concentration, survival time lengthened with decreased waste concentration. A critical concentration was found between 1:5,000 and 1:2,500. This is made clear in the following mortality table.

Experimental Concentration	Time to 50% Mortality
Control I	not reached in 300 hrs.
Control II	not reached in 300 hrs.
1:10,000	not reached in 300 hrs.
1: 5,000	not reached in 300 hrs.
1: 2,500	188 hrs.
1: 1,667	150 hrs.
1: 1,250	130 hrs.
1: 1,000	157 hrs.

Reasons for the mortality of *E. parma* could not be determined from this preliminary experiment. The critical mortality concentration was correlated with iron levels of between 9.4 and 18.8 mg/l in addition to that already present in the water. Data from dispersion studies show background iron concentrations in the disposal area to be in the range of 0.01-0.11 mg/l. Thus, background levels in the water are negligible when compared with the magnitude of the experimental figures above. Iron concentrations of up to 24 mg/l have been found at the surface of the water column in the wake of the barge, but are rapidly reduced by dilution.

Low pH may also be an important factor contributing to mortality in the higher concentrations used. Figure 22 shows the rapid recovery of pH after addition of the waste. A second experiment showed that virtually all of the pH rise is due to the presence of *E. parma* in the experimental tank and not to the buffering action of sea water. Tanks with concentrations of 1:1,250 and 1:1,000 maintained constant pH (3.45 and 3.0 respectively) for 100 hours in the absence of *E. parma*. When the contents of these tanks were split and *E. parma* added to one of the halves (3 sand dollars/2 liters), pH began to rise within 3 hours (Figure 22). It appears likely that dissolution of calcium carbonate from the sand dollar test may be important in the rapid rise of pH after addition of high acid concentrations. Likewise, the dissolution coupled with associated disruption of the epidermis may contribute to the observed mortality. We would not expect this to happen in the ocean site as rapid dilution generally keeps the pH above six.

Animals used in this experiment were bright red-pink color. After exposure to the higher concentrations of acid-waste, the color changed to a dark red. This then progressed to brown, and finally a gray-brown color. Development of the gray-brown was sometimes more rapid on the oral surface than the aboral surface. As the animal neared presumptive death, green blotches were seen in the grooves leading to the mouth on the oral surface. At death many spines fell from the animal. Progression into or through this color change was seen in all experimental animals exposed to the waste. The speed of color change was clearly correlated with the concentration of the waste. Rapid changes occurred in high concentrations while low concentrations produced slower changes which did not go beyond the dark red or brown stage at the termination of the experiment.

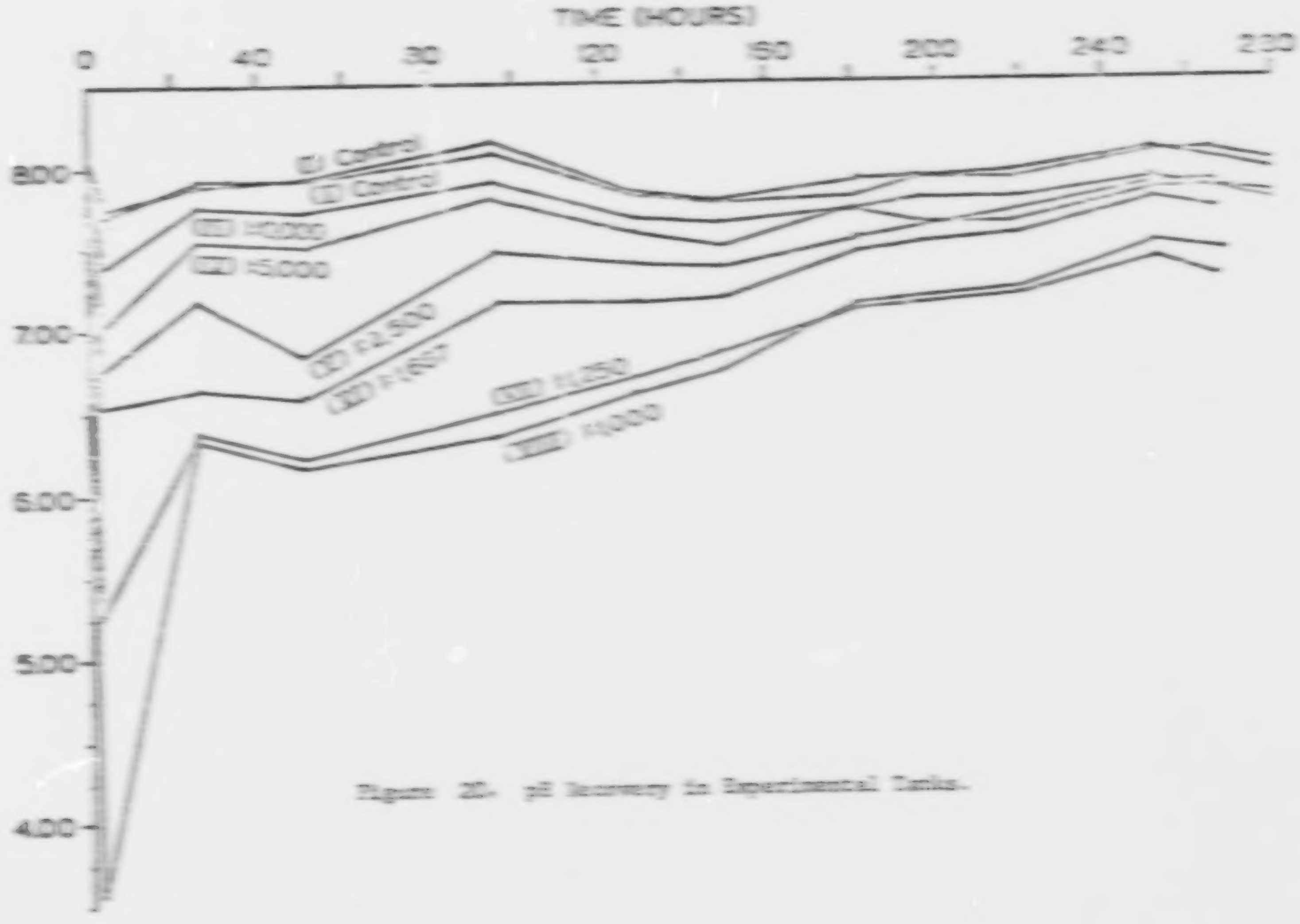


Figure 20. pH Recovery in Experimental Tanks.

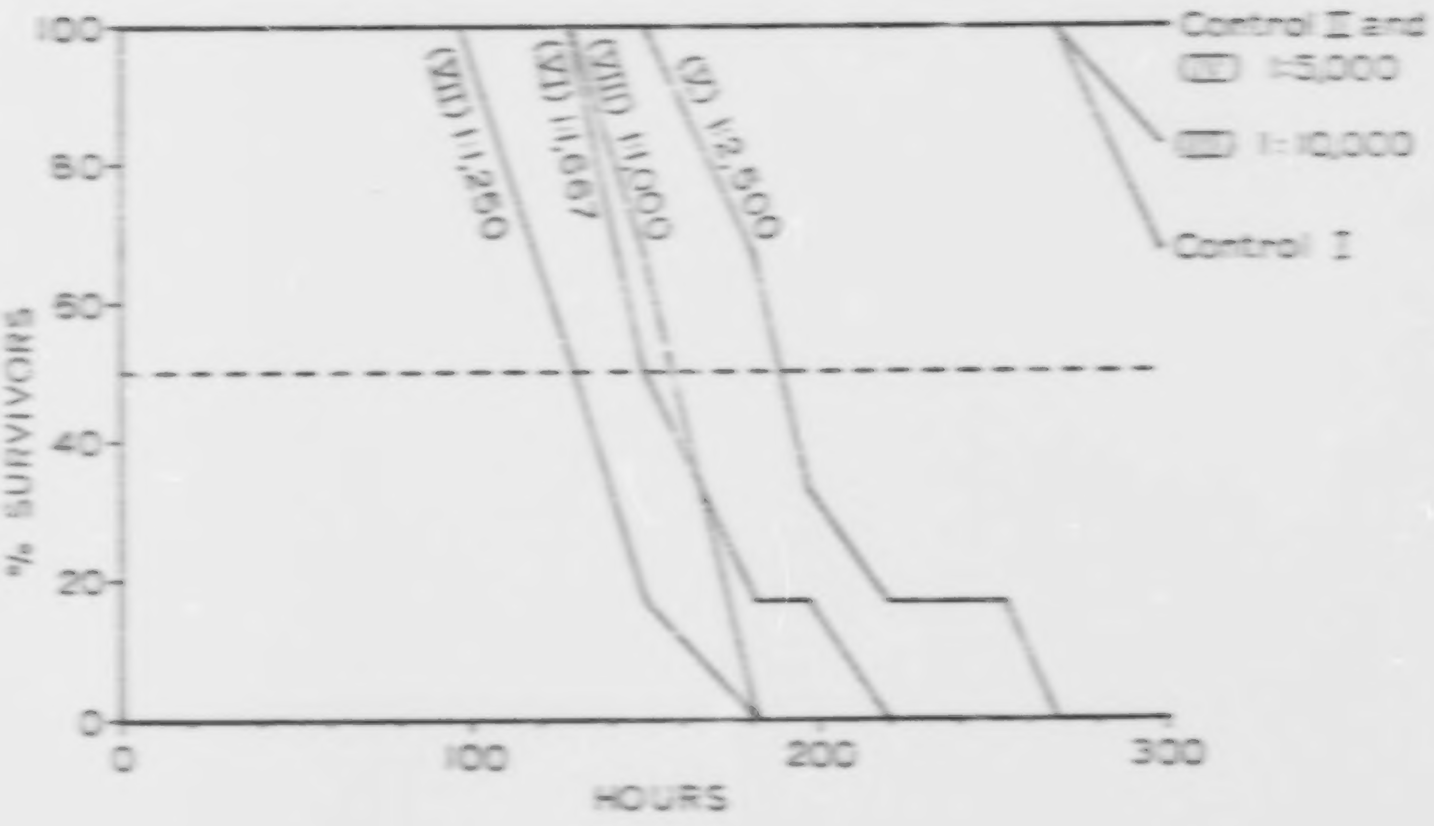


Figure 21. Survival of [illegible] in Iron-Acid Waste.

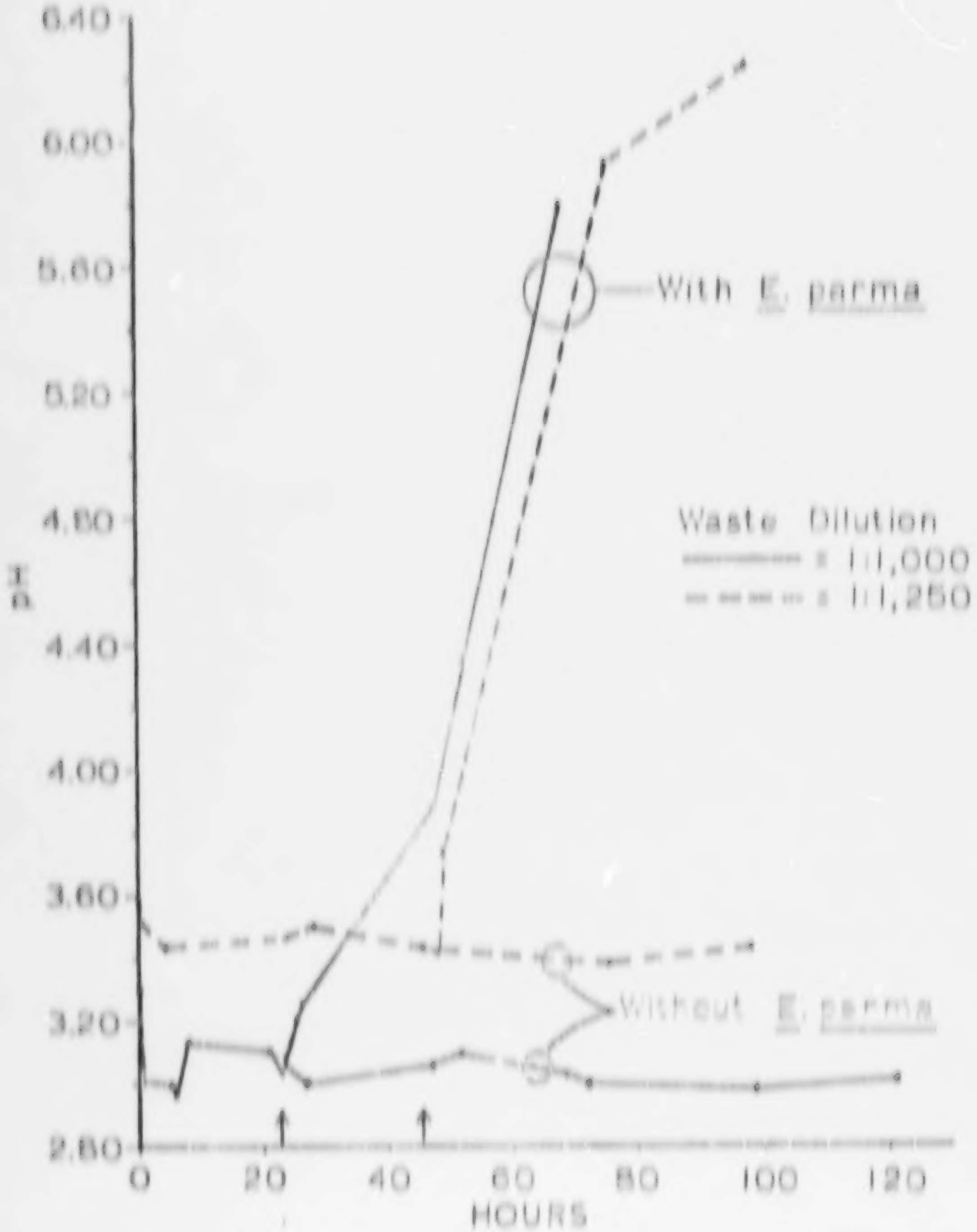


Figure 32. Effect of *Echinorachnius parma* upon pH of acid waste. Arrows indicate time of addition of *E. parma* to waste.

SECTION V-I

GENERAL CONCLUSIONS AND RECOMMENDATIONS ON MARINE EFFECTS

CONCLUSIONS

1. During the period of the monitoring program, no substantial changes were observed in the species composition or the abundance of the biota in the study area which could definitely be attributed to the presence of the waste disposal operation.

2. Phytoplankton and zooplankton composition was similar throughout the disposal area at any given time. No single station appeared to show progressive difference from the others. A seasonal phytoplankton cycle was found, with a dominant dinoflagellate regime in warm seasons (thermocline present) and a diatom regime in cold seasons coincident with a homogeneous water column. Zooplankton were dominated by calanoid copepods and cladocerans. High plankton volumes were found in the spring and fall, due to influx of warm water species, abundant growth in response to phytoplankton blooms, and production of meroplanktonic larvae. These larvae were of groups representing dominant benthic organisms, in and adjacent to the disposal area.

3. Macrobenthic organisms were broadly similar at all stations at a given time. Numerical dominance was found in the northern sand dollar, *Echinarachnius parma*, the sand shrimp, *Crangon septemspinosum*, the ascidean, *Bostrichobranchus pilularis*, and the arenaceous foraminiferan *Astrorhiza*. Coefficient of community index suggests that stations 2 and 8 were becoming progressively more unlike with time, but the rate was very slight and the biotic changes contributing to it could not yet be clearly identified.

4. Station 3 at the southern end of the disposal area usually showed least affinity of the 5 stations. This was found in the predisposal survey as well as during the monitoring program. This may be related to different sediment characteristics within this area.

5. The predisposal survey showed that the commercial surf clam, *Spisula solidissima*, was found only at station 2, and in very low numbers. Patchy accumulations of shells of this species were found throughout the disposal area, and presumably have been transported in from adjacent commercial clamming areas to the north. No living mahogany clams, *Arctica islandica*, were found in the center of the disposal area in the predisposal survey.

6. Bottom sediments in the waste disposal area were found to be fine to coarse sands, moderately well sorted, and with cumulative sediment distribution curves skewed toward coarse fractions. Mean particle size in the sample series ranged from 0.21-0.59 mm. Sediment pH ranged from 7.1 to 7.5. Sediment iron values ranged from 3.9 to 7.1 mg/gm and do not suggest any appreciable increase over values reported from the New York Bight area. Iron concentration was found to be approximately four times greater in the fraction of sediments finer than 62μ than in the coarse fraction.

7. Mortality of sand dollars, as estimated by percentage dead tests, was markedly higher during winter months than summer. It is unclear whether this mortality is related to increased waste penetration during periods of homogeneous water, or to normal mortality of the sand dollar, perhaps following autumnal spawning.

8. Preliminary laboratory tolerance studies indicated mortality in adult sand dollars at waste concentrations greater than 1:2,500 (=18.8 mg Fe/liter). Predictions from the dispersion model suggest maximum winter bottom concentrations of iron would be about 0.9 mg/liter, approximately 20 times less than the critical mortality concentration as determined in laboratory experiments.

9. During late spring and summer, there is the possibility of northerly drift of surface water in the disposal area. One such period was seen in drift bottle releases of May 1969. During such conditions of circulation, some waste would move north, particularly since it would not readily penetrate the thermocline. Prevailing bottom currents appear to be southwesterly at all times of the year.

RECOMMENDATIONS

1. Field monitoring of the waste disposal operation should be continued to identify any long-term changes in the biota of the area. The monitoring program should be carried out twice a year, once during summer when waste settles on the thermocline, and again in winter when waste moves directly to the bottom and in higher concentrations. Additional sampling stations should be established southwest and north of the present station grid. These areas reflect directions in which currents may move waste material. Since the principle biotic associations have now been determined, the scope of subsequent surveys might be expanded to include the effects of waste upon rate functions of broad spectra of organisms.

2. Although no catastrophic, short-term changes have occurred as a result of this waste disposal operation, no information was developed on the metabolic effects of iron and associated heavy metals added to the marine environment in this operation. To better understand the effects of the waste upon biota, especially long-term sublethal, controlled laboratory experiments should be developed to evaluate the effects of the waste and its constituents on feeding, metabolism, reproduction, and behavior of selected marine organisms. Such information will be necessary before meaningful guidelines can be developed for maximum permissible waste loads in a given area.

SECTION VI

BARGING COST

Barging costs were developed for the Edge Moor operations for the first eight months of 1971. Included are drydock overhaul costs and painting, and barge dock dredging, both done three years after the barge began operation. These were prorated for eight of that 36-months period. Not included are costs associated with monitoring studies of the barge operations.

The round trip to the disposal area is 200 nautical miles. At 5,000 tons/trip, the ton-miles (nautical)/trip is 1,000,000.

The barge was specially built for this waste disposal operation at a cost of 1.1 million dollars. It is shown, however, as a barge leasing item since actual ownership is not in the hands of the Edge Moor plant. The depreciation shown is for shore facilities, dock, etc., used in the barging operation.

The following categories were established in analyzing costs:

Category	Description
A	Operating Labor and Supervision
B-1	Normal Maintenance Labor and Supervision
B-2	3-year Overhaul Maintenance & Dredging
B-3	Repair materials and mill supplies
C	Barge leasing
D	Barge towing plus towing company services

Category	Description
E	Depreciation weighted average rate of 7.2%.
F	Insurance, taxes, miscellaneous

Table 29 shows the total costs for each category on per ton-mile (nautical), per ton, and per trip bases.

TABLE 29
UNITIZED BARGING COSTS

Category	Per Cent of Total	Ton-Miles*	Cost Per Ton	Trip
A	4.9	0.0185¢	3.70	$ 185
B-1	6.1	0.0230	4.59	230
B-2	4.1	0.0158	3.16	158
B-3	4.1	0.0155	3.11	155
C	24.4	0.0923	18.47	923
D	45.4	0.1719	34.38	1,719
E	9.2	0.0350	7.00	350
F	1.8	0.0067	1.34	67
TOTALS	100.0	0.3787	75.73	$3,787

* Nautical mile. To convert to cost per ton-mile (statute), multiply by 0.87. Thus, the total cost per ton-mile (statute) is 0.329¢.

To get costs per thousand gallons, multiply this column by 1,000. Thus, total cost/1,000 gallons is $3.79. This conversion can be made since, coincidentally, the barge volume in gallons numerically about equals the ton-miles (n) per trip.

SECTION VII

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SECTION VIII

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APPENDIX A-1

SUMMARY OF OCEAN CRUISES

CRUISE K-01-69 MAY 14, 15, 1969

Description and Purpose

Cruise K-01-69 was conducted prior to the initiation of waste discharge in the designated disposal area, to obtain baseline physical, chemical, and biological data from which any future changes could be detected. The cruise also served to familiarize personnel with the disposal area and determine necessary procedures for future sampling.

The first cruise day was devoted to obtaining temperature, salinity, light penetration and current data, and collection of water samples for analyses. On the second day, the University of Delaware Marine Laboratory personnel collected biological data. Underwater television scanning and monitoring of bottom conditions was also conducted to aid in the examination of the benthos and to provide a permanent record of the state of the sea bottom.

Winds during the first day of sampling were generally calm to light and variable throughout the day out of the southwest at 0-5 mph. The sky was overcast in the morning hours becoming partly cloudy around 1500 EDT.

Tables A-1 and A-2 summarize physical and chemical data collected on May 14, 1969. A typical temperature-salinity profile is shown in Figure A-1. Some current information obtained with an Ekman current meter are summarized in Table A-3. Velocities on the order of one knot appeared questionably high, especially at the lower depths. A string of Carruthers current measuring devices was placed at station 8, but recorded

TABLE A-1

DATA OF BACKGROUND STUDY
Cruise K-01-69, May 14, 1969
Research Vessel KIMA

Station	Depth (meters)	Temp. (°C)	Salinity (0/00)	Chlorides (0/00)	pH	Alkalinity as $CaCO_3$ (mg/l)	D.O. (mg/l)	Total Iron (μg/l)	Total Phosphates (mg/l-PO_4)	Nitrate (mg/l-N)	Kjeldah Nitroge (mg/l-N
2	1	11.3	32.74	19.35	8.20	114	9.1	66.	.005	.002	0.26
(0730*	15	10.3	32.78	18.75	8.75	——	9.3	30.	——	.006	0.18
33M⁺)	30	7.2	33.01	19.50	8.55	116	9.1	46.	.005	.002	0.22
4	1	12.0	32.97	18.15	8.55	115	9.3	44.	.005	.006	0.34
(0920*	19	10.3	32.99	18.80	8.63	116	9.1	31.	.020	.0025	
41M⁺)	38	6.7	33.29	20.15	8.58	——	9.3	44.	.010	.0015	
5	1	12.0	32.91	18.10	8.60	114	9.1	41.	.005	.018	
(1130*	20	7.6	33.01	18.80	8.58	116	9.2	59.	.005	.007	
43M⁺)	40	7.1	33.26	19.15	8.60	118	9.2	48.	.021	.0025	
6	1	11.2	32.97	18.85	8.50	116	——	50.	.005	.0015	0.31
(1240*	19	8.7	33.01	18.70	8.58	116	9.7	51.	.005	.001	
41M⁺)	38	7.1	33.23	18.90	8.55	——	9.0	44.	.015	.001	
8	1	11.3	32.99	18.80	8.60	115	9.4	61.	.005	.0025	
(1020*	17	9.6	33.01	18.90	8.68	115	9.9	36.	.705	.0025	
38M⁺)	35	6.8	33.28	18.45	8.63	——	9.3	113.	.005	.037	

*Eastern Daylight Saving Time.

⁺Total Depth

TABLE A-1
(continued)

DATA OF BACKGROUND STUDY
Cruise E-01-69, May 14, 1969
Research Vessel KYMA

Station	Depth (meters)	Temp. (°C)	Salinity (0/00)	Chlorides (0/00)	pH	Alkalinity as $CaCO_3$ (mg/l)	D.O. (mg/l)	Total Iron (μg/l)	Total Phosphates (mg/l-PO_4)	Nitrate (mg/l-N)	Kjeldahl Nitrogen (mg/l-N)
11	1	12.5	——	18.26	8.50	110	8.7	90.	.005	.014	
(1545*	10	9.6	——	——	——	——	——	——	——	——	
21m+)	20	9.4	——	——	——	——	——	——	——	——	
13	1	13.7	——	18.10	8.65	106	8.3	320.	.01	.0025	0.52
(1455*	5	12.8	——	——	——	——	——	——	——	——	
9m+)	8	12.5	——	——	——	——	——	——	——	——	

*Eastern Day Light Saving Time.

+Total Depth

TABLE A-2

PERTINENT COMPUTED VARIABLES

Cruise K-01-69 - May 14, 1969
Research Vessel KYPA

Station Number and Description	Depth (M)	σ_t	Extinction Coefficient $(ft)^{-1}$
2 Depth = 110 ft.	1 15 30	24,988 25,137 25,848	,031
4 Depth = 135 ft.	1 19 38	25,031 25,355 26,136	,037
5 Depth = 140 ft.	1 20 40	24,988 25,794 26,053	,021
6 Depth = 135 ft.	1 19 38	25,179 25,626 26,036	,0334
8 Depth = 125 ft.	1 17 35	25,190 25,490 26,120	,038
11 Depth = 69 ft.		------	,128
13 Depth = 30 ft.		------	,350

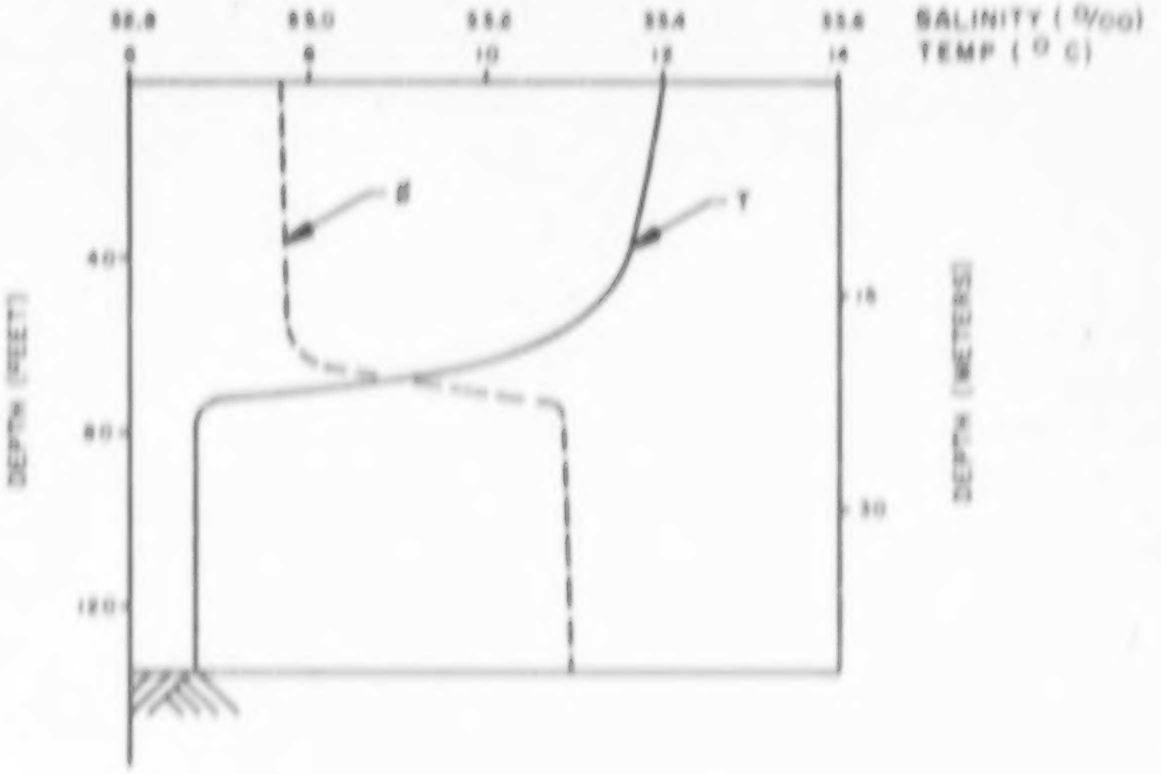


FIGURE A-1

VERTICAL TEMPERATURE & SALINITY PROFILE

CRUISE K-01-69 - STATION # 4, MAY 14, 1969

TABLE A-3

CURRENTS
(Ekman Current Meter)
Cruise K-01-69 May 14, 1969
Research Vessel KYMA

Station	Depth (ft.)	Approximate Speed (knots)	Direction (Degrees-True)
5	0	1.0	21
	12	0.8	28
6	0	1.0	163
	10	1.1	150
	40	1.0	138
	70	0.9	116

no measureable current. Doubt about the high current measurements led to a decision to use continuous current meters during future surveys.

Discussion and Summary

The computed sigma-t values listed in Table A-2 show increasing density with depth, a stable stratified system. A well-defined two-layer system existed with warmer, less saline water extending to about mid-depth and cooler, more saline water beneath (Figure A-1).

Table A-2 shows light extinction coefficients ranged from about 0.02 to 0.04 ft^{-1} at all stations. The data also indicate relatively clearer water below the thermocline than above. The coefficients at the in-shore stations (numbers 11 and 13) probably reflect the effect of Delaware River runoff. An order of magnitude increase in the coefficient is noted between the discharge area and the mouth of Delaware Bay.

The chemical data were generally consistent with that expected. Dissolved oxygen was supersaturated in the surface layers and slightly undersaturated in the bottom waters. Iron concentrations were generally consistent with values observed in the New York Bight. Some indication of the outflow from Delaware Bay was noted in that 320 µg/l of iron was measured at the mouth.

CRUISE K-02-69 OCTOBER 10-11, 1969

Description and Purpose

This cruise initiated the waste sampling in the barge wake. On October 10, 1969, dispersion studies were conducted in two phases: at barge speeds of 6 and 3 knots. The purpose was to obtain information on waste dispersion during a thermocline weakening period. Collection of background chemical and biological data was done on October 11. Continuous current meters were operated at two depths at Station 5.

Temperature measurements indicated a deep thermocline extending from about 100 feet to 115 feet. A typical temperature-salinity profile is shown in Figure A-2. Note the unusual salinity profile at this station, probably due to the intermixing of different offshore water masses due to the passage of tropical storms.

Dispersion Studies

During the first dispersion run, Line A, waste was discharged for approximately 20 minutes at a normal barge speed of about 6 knots in a west to east discharge pattern. The remainder of the barge waste load was discharged during Line B, approximately 3 hours later, in a similar discharge pattern a few miles north at a barge speed of about 3 knots. The weather was essentially clear with approximately one-tenth cloud cover and winds about 10 knots from the north-northwest. Sea swells were about two feet to the southeast. Table 4 shows the waste characteristics.

Cross-sections of both Lines were monitored for about two hours. Nineteen stations were sampled for Line A and 23 for B. For both Lines, the positions of the centerline stations (Figure A-3) indicated a general drift of the visual waste plume to the southwest (about 200°). The distances covered from the start of observations were approximately 2.7 nautical miles for both Lines.

The centerline iron concentrations in Line A were less than 5 μg/l (detectable limit) at the 50-foot and 100-foot depths, and did not exceed 200 μg/l in the surface samples. These results have not been plotted. In general, the pH and alkalinity measurements for Line A showed no marked deviation from background levels.

Figure A-4 shows iron concentrations along the assumed centerline of Line B, as a function of time and depth. During the last hour of sampling, iron concentrations measured at the 50-foot depth north of the visual centerline of the waste plume were substantially higher than those measured along the visual centerline at 50 feet. This was probably caused by current directional shear over the depth of the water column. These higher values are probably indicative of the actual centerline of the waste field at the 50-foot depth and have been incorporated into Figure A-4. This Figure shows the highest iron concentrations were near the 50-foot depth.

The data indicate the waste did not penetrate the thermocline in substantial concentrations. The lowest sampling depth,

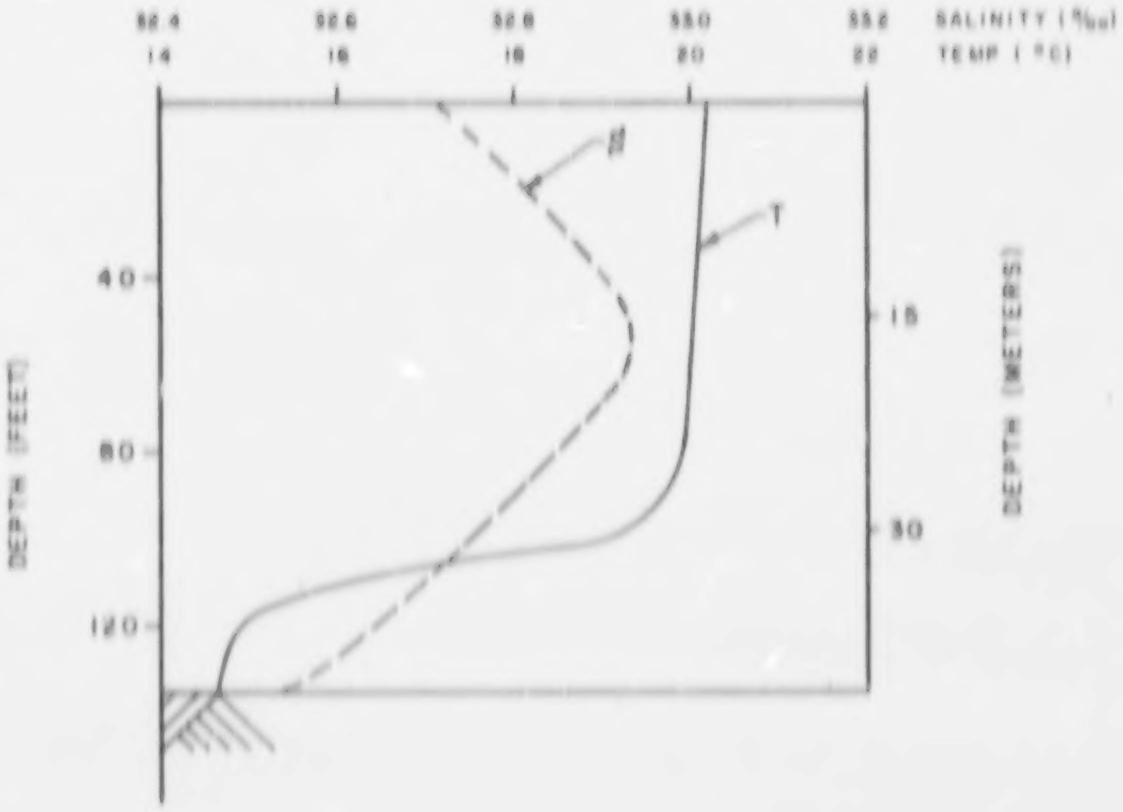


FIGURE A-2

VERTICAL TEMPERATURE & SALINITY PROFILES

CRUISE K-02-69 STATION #5, OCTOBER 11, 1969

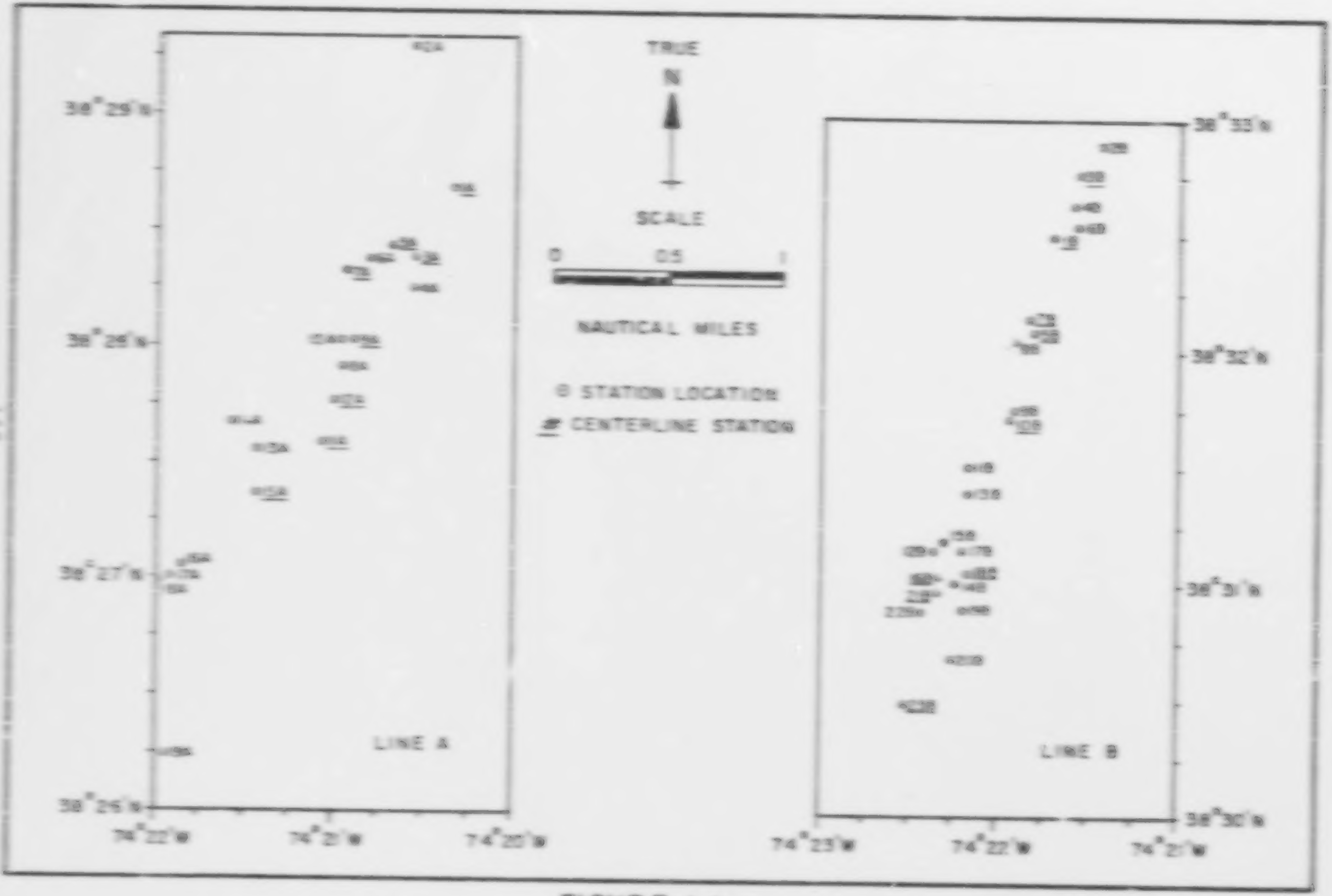
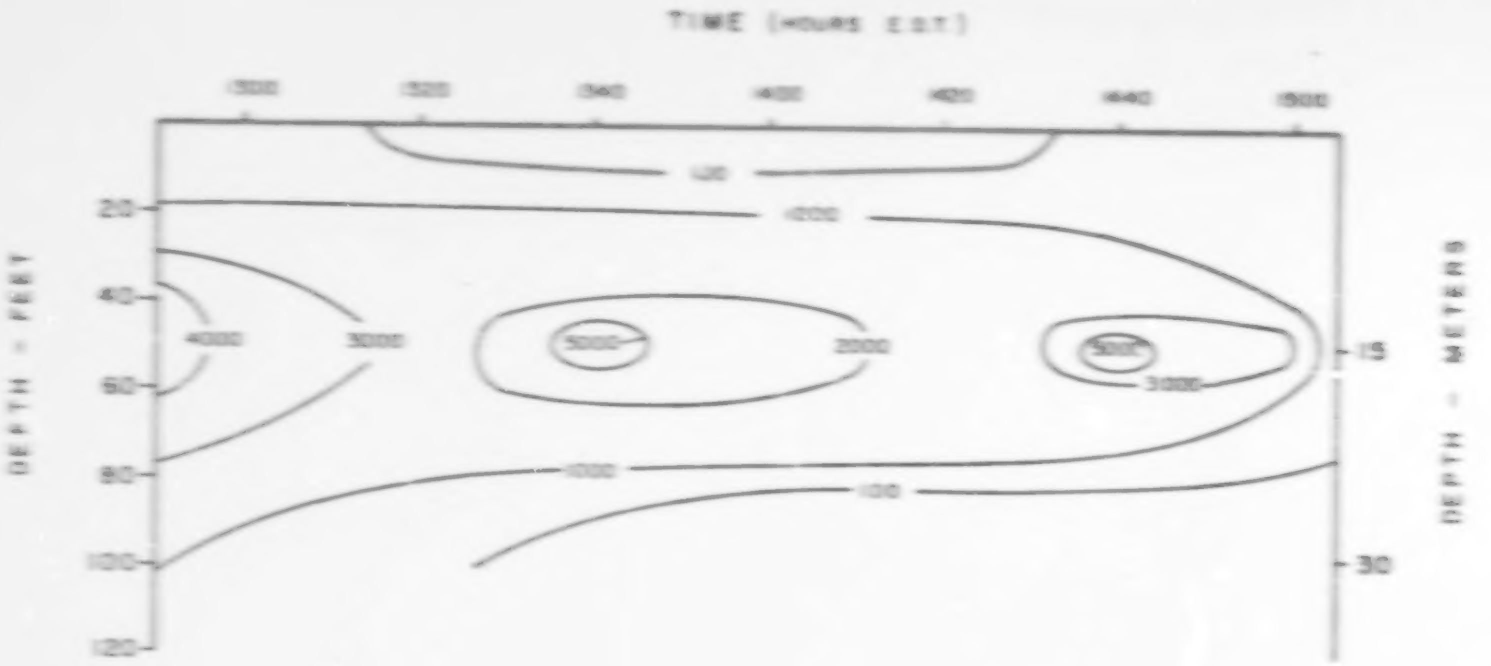

38°29'N
38°28'N
38°27'N
38°26'N
74°22'W
74°21'W
74°20'W
LINE A
TRUE
N
SCALE
0
0.5
1
NAUTICAL MILES
⊙ STATION LOCATION
# CENTERLINE STATION
38°33'N
38°32'N
38°31'N
38°30'N
74°23'W
74°22'W
74°21'W
LINE B

FIGURE 4-3
POSITIONS OF SAMPLING STATIONS
CRUISE K-02-69 OCTOBER 10, 1969



RAW WASTE IRON CONCENTRATION = 27.9 GM/L

BARGE SPEED = 3 KNOTS

FIGURE A-4
TOTAL IRON (µG/L) ALONG CENTERLINE
CRUISE K-02-69 LINE 8 OCTOBER 10, 1969

100-feet, showed only one iron concentration above the 100 µg/l background level. The pH and alkalinity measurements for Line B generally concur closely with the iron data, i.e., lower values of pH and alkalinity occurred at the 50-foot depth. The lowest pH (5.5) and alkalinity (44 mg/l $CaCO_3$) values were measured at this depth. Both pH and alkalinity for Line B approached background levels at the end of the two-hour sampling period.

The pH, alkalinity, and iron data obtained during Line A indicate the effect of the waste was relatively minimal. During this survey, the waste plume was relatively patchy and functional problems with the mid-depth Kemmerer sampler were encountered. The data from Line B indicate a more pronounced effect of the waste. At the slower barge speed, higher iron concentrations would be expected. However, the samples were not preserved with acid during this cruise. Considering the above factors along with the inexperience of the personnel with this type of field study, the validity of the information collected on this cruise is somewhat questionable.

Background Study

The background study of October 11 was seriously hampered by heavy seas from the northward movement of hurricane Kara. Stations 5, 6, and 8 were completed before weather curtailed the survey. Table A-4 summarizes the water column chemical data collected. No change was evident with respect to iron when compared to the data obtained during Cruise K-01-69. Higher total phosphates and lower Kjeldahl nitrogen values were found. Dissolved oxygen values were supersaturated in the surface layers and somewhat undersaturated in the bottom waters. Light penetration studies conducted only at stations 5 and 6 yielded extinction coefficients of 0.03 and 0.06 ft^{-1}, respectively. The increased turbulent at the latter station probably caused the higher extinction coefficient.

Analysis of Current Data

Two continuous mode current meters were operated at station 5 at depths of about 30 feet and 94 feet for 30 hours and 50 minutes beginning at 0745 EDT, October 10. Unfortunately, the film recording the current data was totally overexposed in

TABLE A-4

DATA OF BACKGROUND STUDY
Cruise K-02-69, Oct 11, 1969
Research Vessel KYMA

Station	Depth (Meters)	Temp. (°C)	Salinity (0/00)	pH	Alkalinity as $CaCO_3$ (mg/l)	D.O. (mg/l)	Total Iron (μg/l)	Total Phosphates as P (mg/l-PO_4)	Kjeldahl Nitrogen (μg/l-N)
45	1	20.2	32.709	8.1		8.0	30.	----	<2
(1330,*	18	20.0	32.943	8.2	125	7.8	70.	.29	<2
42 M+)	37	15.0	32.639	8.0	124	5.7	65.	.13	<2
46	1	20.6	31.912	8.1	116	8.0	25.	.46	<2
(1945,*	18	20.4	32.111	8.1		8.3	30.	.31	<2
45 M+)	37	15.4	32.514	8.1		4.9	25.	.32	<2
48	1	20.1	31.869	8.2	125	7.8	20.	.23	<2
(1715,*	18	20.6	33.018	8.2	125	7.8	110.	.40	<2
42 M+)	37	14.8	32.645	8.1	125	5.35	30.	.27	<2

*Eastern Daylight Savings Time

+Total Depth

the bottom meter, and partially so for the top meter. Figure A-5 shows a polar coordinate histogram plot of the results from the top meter. It shows a somewhat variable directional drift, probably caused by a rotary tide in the area, with a preference to the southwest. Speed averaged about 0.8 knots. This is in approximate agreement with the observed movement at the waste plume during the dispersion runs.

Summary

This cruise initiated personnel in techniques for tracing the dispersion of wastes. The greater possibility of error was recognized and the relative importance placed on these studies should be less than that placed on later studies. Nevertheless, the data does imply that at the slower barge speed, the waste (as measured by iron) appears to penetrate into deeper water, probably due to a larger initial downward velocity. However, penetration of the waste below the vicinity of the thermocline is not indicated. The limited background chemical data indicate no substantial change in the chemical nature of the water column of the study area that can be related to the dumping operations. Current data show the effect of a rotary tide with a general southwest trend of surface waters. Speeds averaged about 0.8 knots.

CRUISE K-03-70 MAY 14, 16, 1970

Description and Purpose

On May 14, 1970, a dispersion study was conducted at a barge speed of about 6 knots. Unfavorable weather caused delay of a background study scheduled for the next day (east winds, 10-20 knots). On May 16, 1970, a second dispersion study was conducted at a barge speed of approximately 3 knots as well as the background study. The dispersion studies were done to obtain information during a period of a developing thermocline.

As during Cruise K-01-69 (May, 1969), a well-defined two-layered system was observed. Figure A-6 shows a typical temperature-salinity profile observed. The thermocline extended from about 40 to 80 feet.

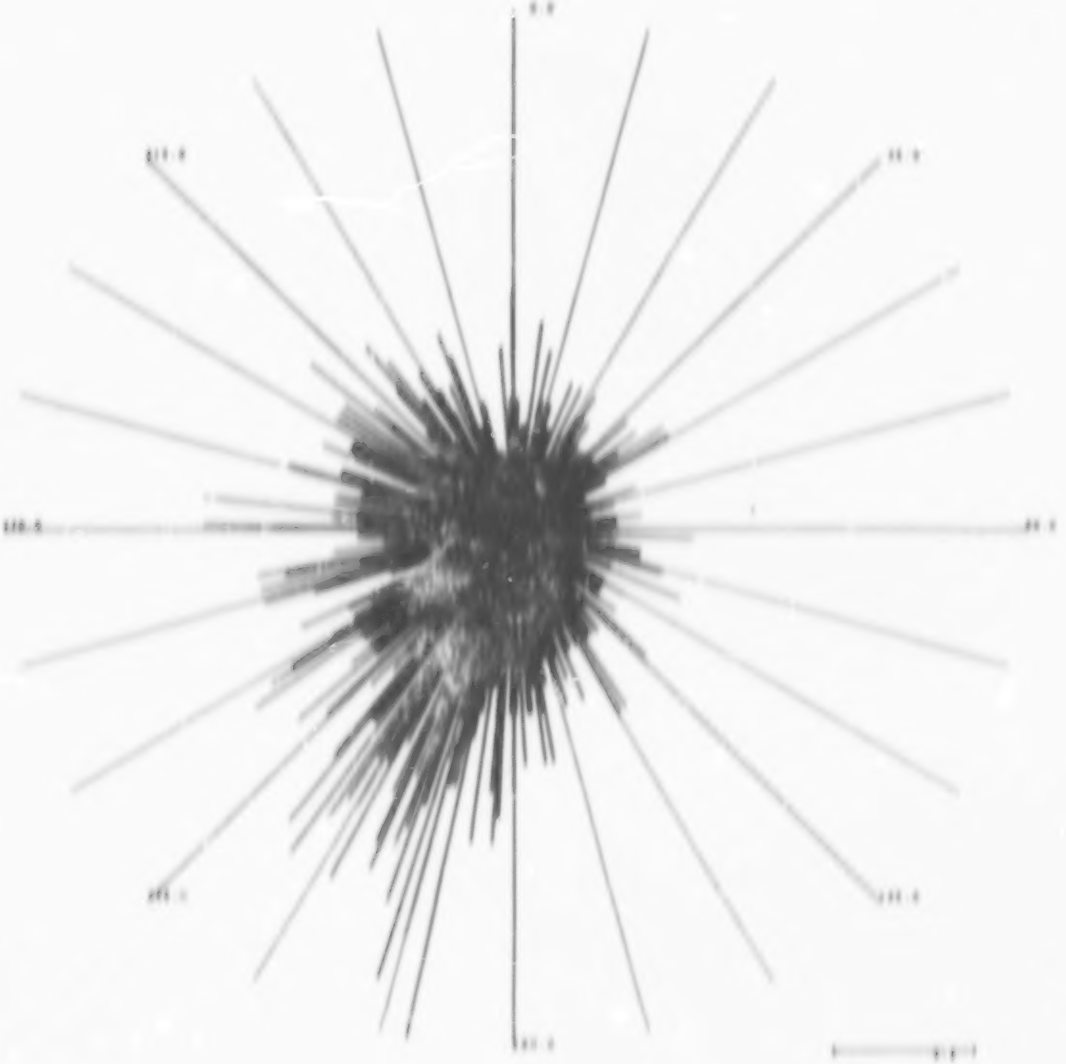


FIGURE A-1
CONTINUOUS CURRENT METER RESULTS
TOP METER - DEPTH ≈ 50 FEET
CRUISE K-02-69 OCTOBER 10,11, 1969

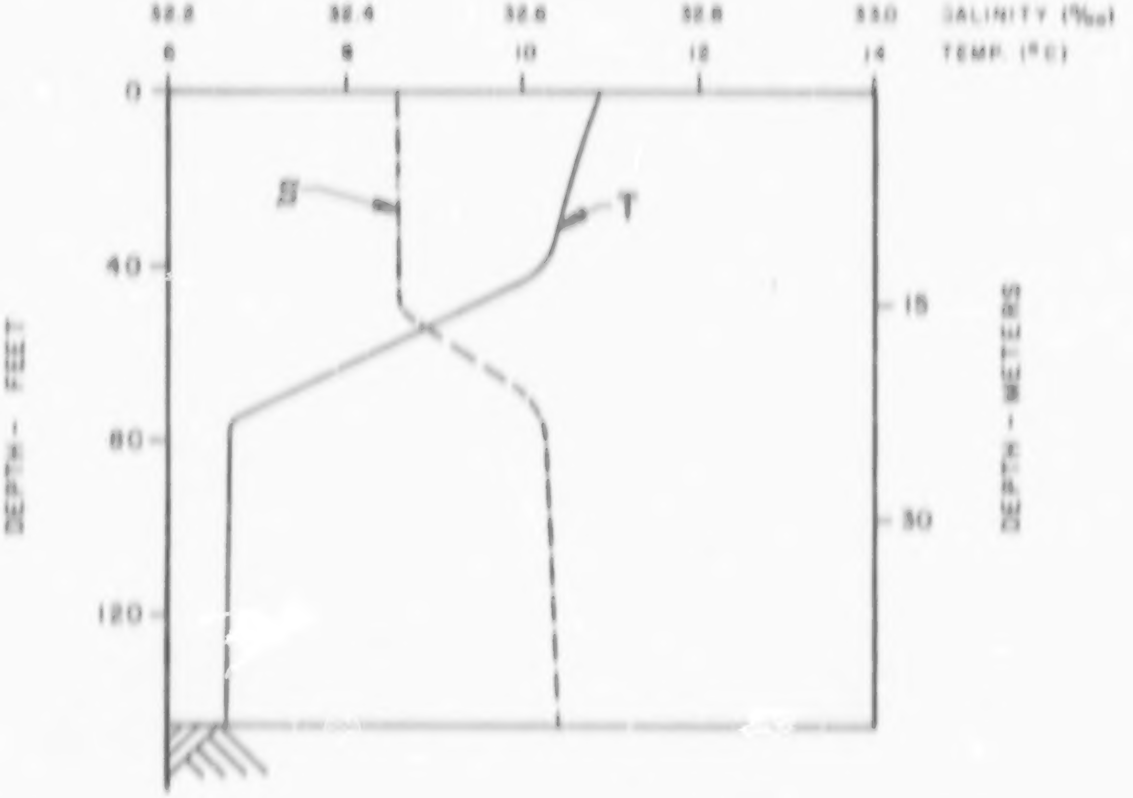


FIGURE A-6
VERTICAL TEMPERATURE & SALINITY PROFILES
CRUISE K-03-70 - STATION 5, MAY 16, 1970

Analysis of Current Data

Three continuous mode current meters at station 5 were placed at depths of 30, 65, and 100 feet and operated for about 55 hours beginning at 0751 EDT, May 14. A partial failure of the mooring anchor resulted in a 34-hour record at the intended depths, and a 21-hour record at about 30 feet above intended depths when the subsurface mooring buoy came to rest on the surface. Figures A-7 through A-9 summarize the data with polar coordinate histogram plots. Eulerian vector plots of the records of the three meters are shown in Figure A-10. The top instrument data was quite variable, both before and after the anchor release. Its data recorded after the anchor release probably reflects the effect of excessive turbulence caused by waves. Many top meter measurements taken after the anchor release exceeded the operating range of 2 knots and were therefore not recorded.

In general, the current data show the effects of a rotary tide. Some directional shear between top, mid, and bottom meters was noted. Considerable velocity shear was demonstrated by the middle current meter record where speeds averaged about 0.5 knots prior to and greater than 0.8 after the anchor release. The drift was generally south-southwest over the depth of the water column. Current speeds over the depth of the water column averaged about 0.6 knots. The maximum net spatial drift recorded (Figure A-10) was about 20 nautical miles for the 55-hour record, corresponding to a net drift velocity of about 0.36 knots (8.7 nautical miles per day).

Dispersion Studies

The conditions of the Line A dispersion study were generally clear skies, with a slight swell, initially calm winds becoming NNW to ENE at about 15 knots by the second hour of sampling. Ground swells as high as ten feet, generally clear skies, and ESE winds at about 8 knots initiated the second dispersion study, Line B. After about one and one-half hours of sampling, a heavy fog swept in, making plume visibility difficult from about 1109 to 1210 hours. Winds decreased to less than 5 knots toward the end of the study.

The waste characteristics (Table 4) indicate the waste for Line A was similar to that for Cruise K-02-69, while that for Line B was slightly less concentrated.

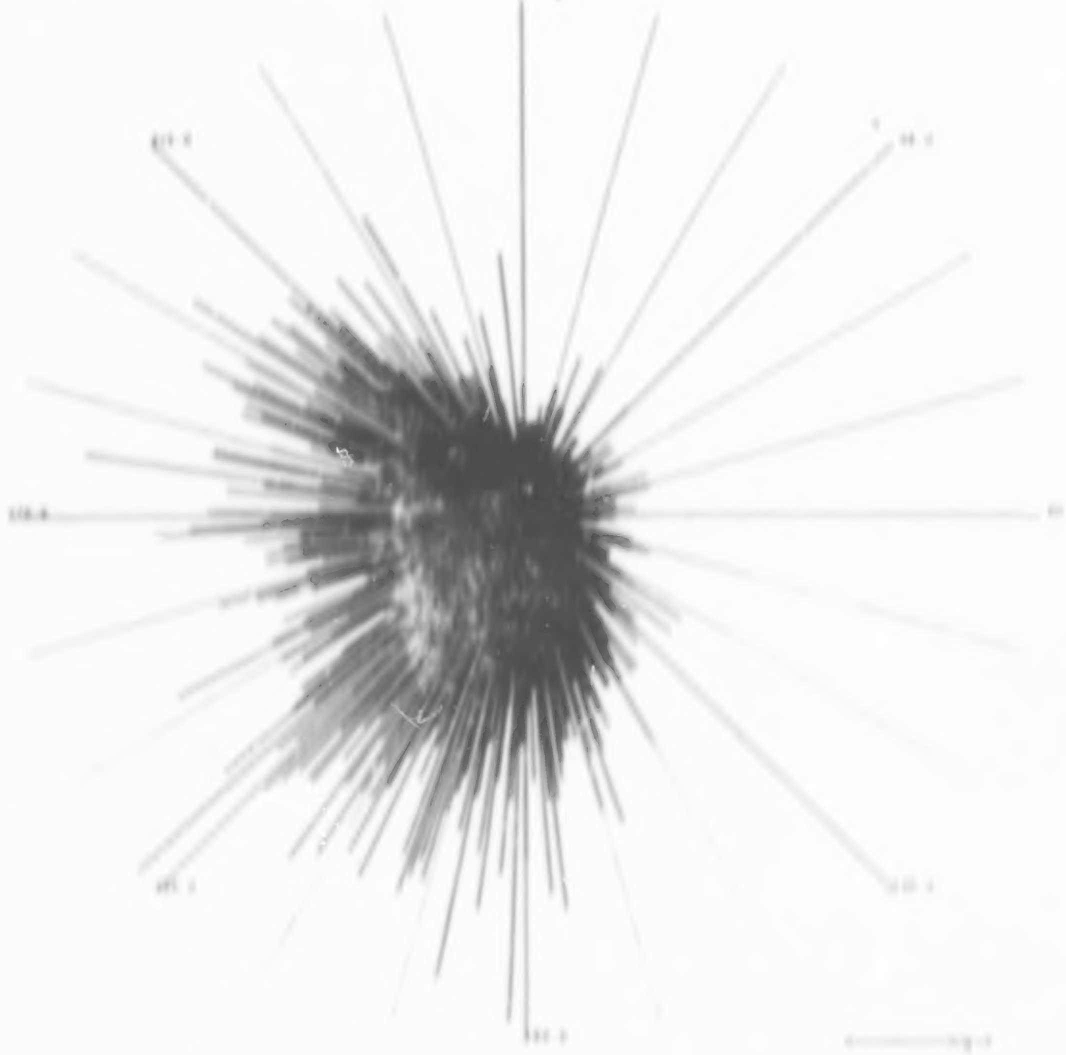


FIGURE A-7
CONTINUOUS CURRENT METER RESULTS
TOP METER
CRUISE X-05-70 MAY 14-16, 1970

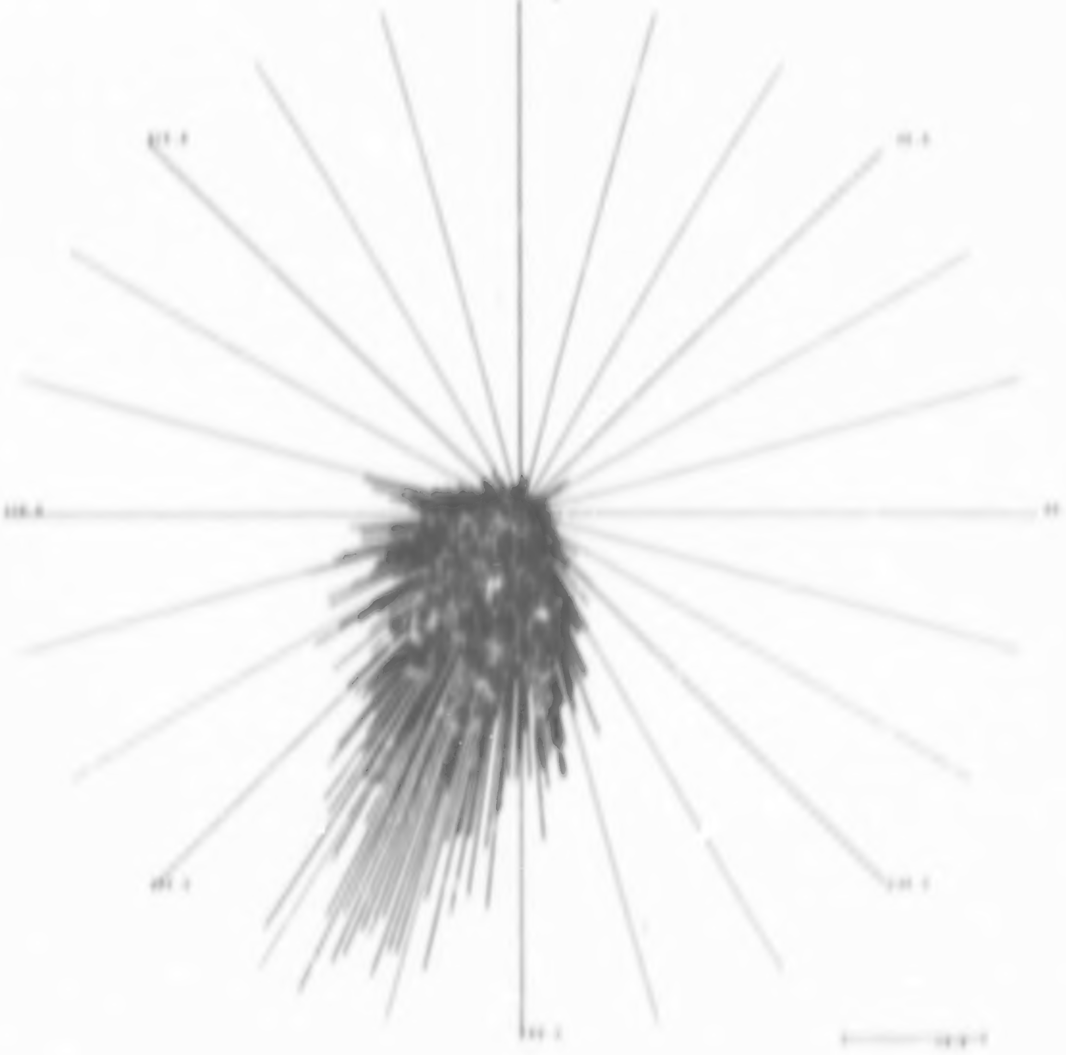


FIGURE A-8
CONTINUOUS CURRENT METER RESULTS
BOTTOM METER
CRUISE X-C 3-70 MAY 14-16, 1970

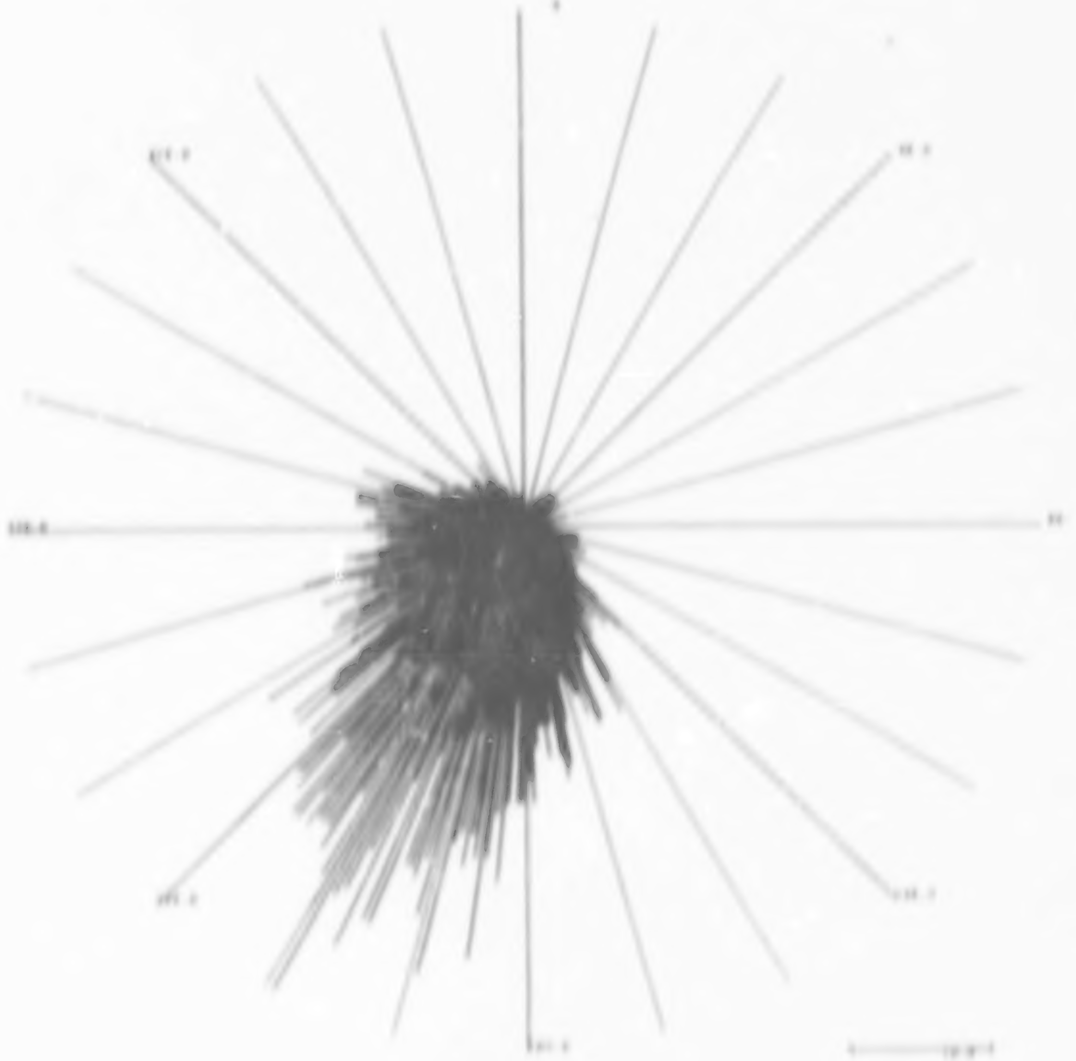


FIGURE A-9
CONTINUOUS CURRENT METER RESULTS
MIDDLE METER
CRUISE K-03-70   MAY 14-16, 1970

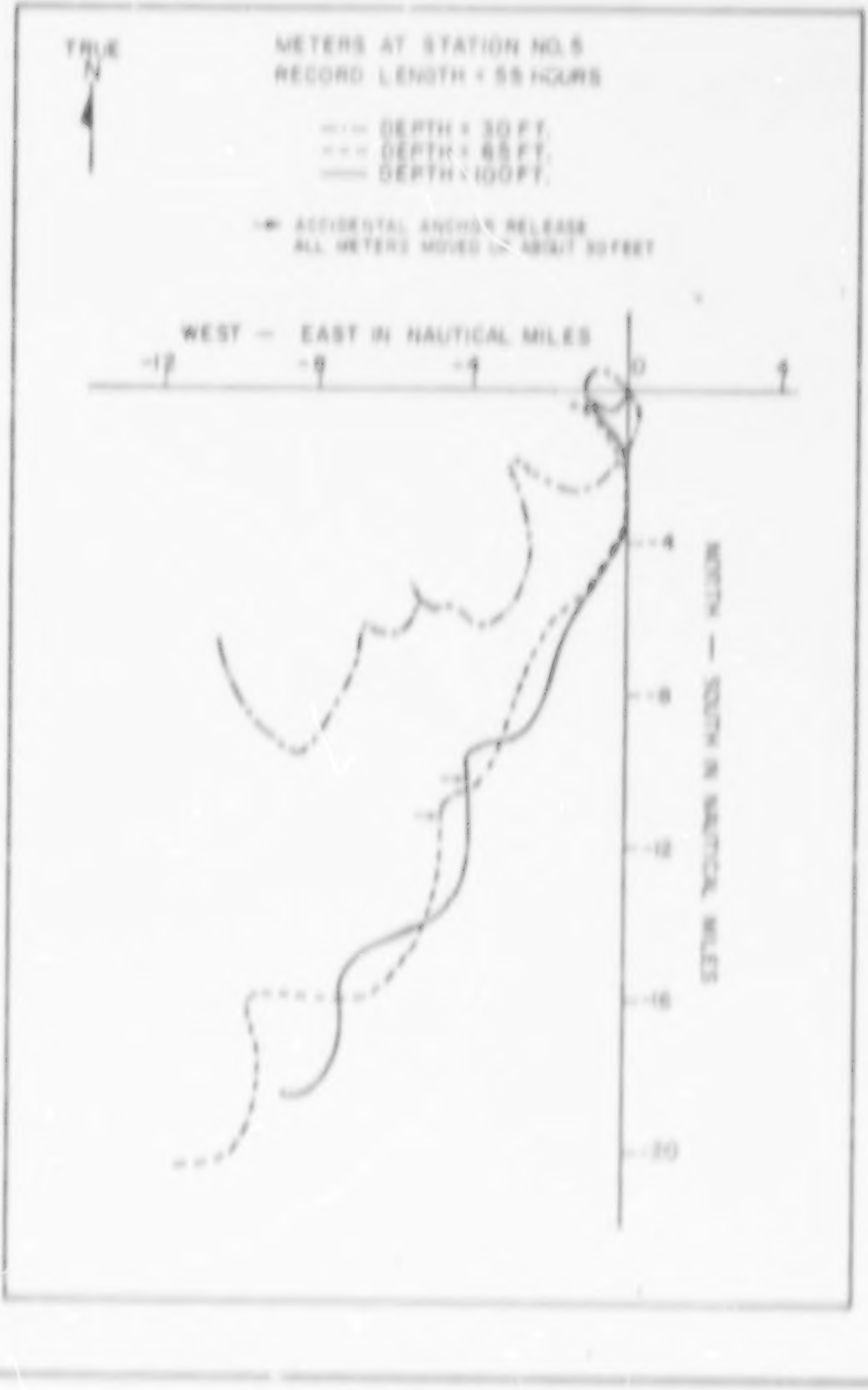


FIGURE A-10
CONTINUOUS CURRENT METER RESULTS
CRUISE K-03-70 MAY 14-16, 1970

A total of 44 stations were sampled for Line A and 34 for Line B. For Line A (Figure A-11), the stations were all grouped relatively closely with little net drift trend. For Line B (Figure A-12), the plume generally drifted to the west. The distance travelled by Line B plume during the four hours of monitoring was about 2.4 miles.

Figures A-13 and A-14 show the iron concentrations along the visual centerline of the waste plumes as functions of time and depth. For both lines, the iron concentrations north and south of the visual centerlines were generally below 100 µg/l indicating that directional shear was not substantial, at least during the limited periods of sampling. For the faster barge speed (Figure A-13), the waste (as measured by iron) remained closer to the surface than for the slower barge speed (A-14). This may be due to the higher immediate downward velocity imparted at the higher initial plume concentrations, concurring with data of Cruise K-02-69. For both Lines, dilutions of the raw waste iron concentrations by about three orders of magnitude were observed to occur within the first twenty minutes after discharge.

On the basis that 100 µg/l Fe represent background conditions, the waste did not reach the ocean bottom for Line A. However, for Line B, a few values above 100 µg/l were measured at the 100-foot depth, indicating that waste may have reached the bottom during the early stages after discharge at the slower barge speed. Iron concentrations were, however, at or near background levels over the depth of the water column, after four hours of sampling Line B. The same relatively rapid return to background levels was generally demonstrated for Line A. However, a single value of 4,000 µg/l Fe was measured at the 25-foot depth toward the end of the sampling period for Line A. This is probably indicative of a small patch of the waste, since the majority of the samples taken two hours previous to this high iron sample were below 100 µg/l Fe.

The initial acidic effect of the waste was noted for Line B where a pH of 3.5 was recorded at the 50-foot depth for the first station. However, both pH and alkalinity returned to background levels in the waste field over the depth of the water column within one hour after discharge. For Line A, the lowest pH and alkalinity recorded were 7.4 and 59 mg/l as $CaCO_3$, respectively. Both pH and alkalinity were near background levels within three to four hours after discharge for Line B.

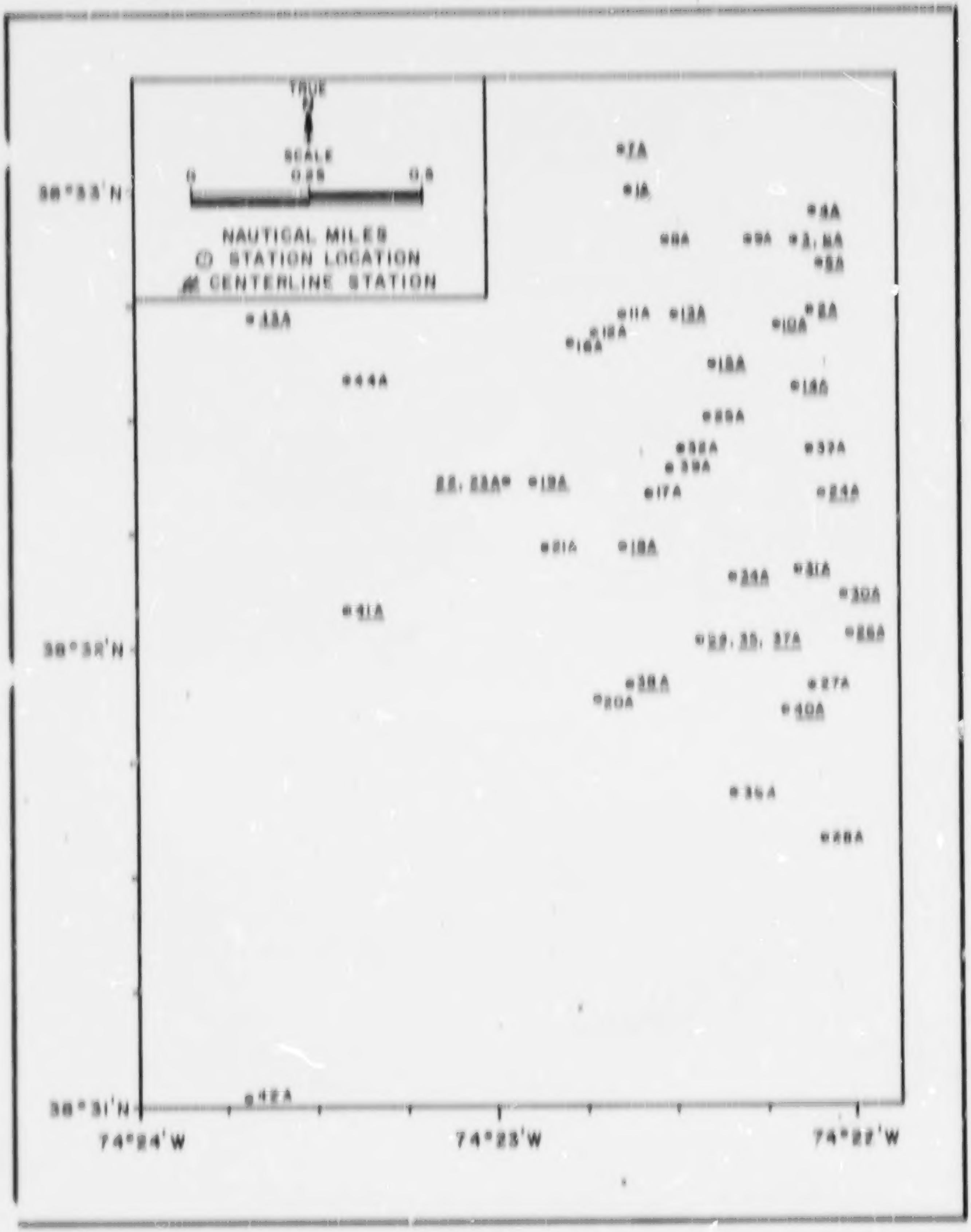

TRUE N
SCALE
0
0.25
0.5
NAUTICAL MILES
⊙ STATION LOCATION
# CENTERLINE STATION
38°33'N
38°32'N
38°31'N
74°24'W
74°23'W
74°22'W
7A
1A
4A
8A
9A
3, 5A
6A
11A
13A
10A
2A
43A
12A
16A
15A
14A
44A
25A
32A
37A
39A
22, 23A
19A
17A
24A
21A
18A
34A
31A
30A
41A
29, 35, 37A
26A
38A
27A
20A
40A
36A
28A
42A

FIGURE A-11
POSITIONS OF SAMPLING STATIONS
CRUISE K-03-70 – LINE A

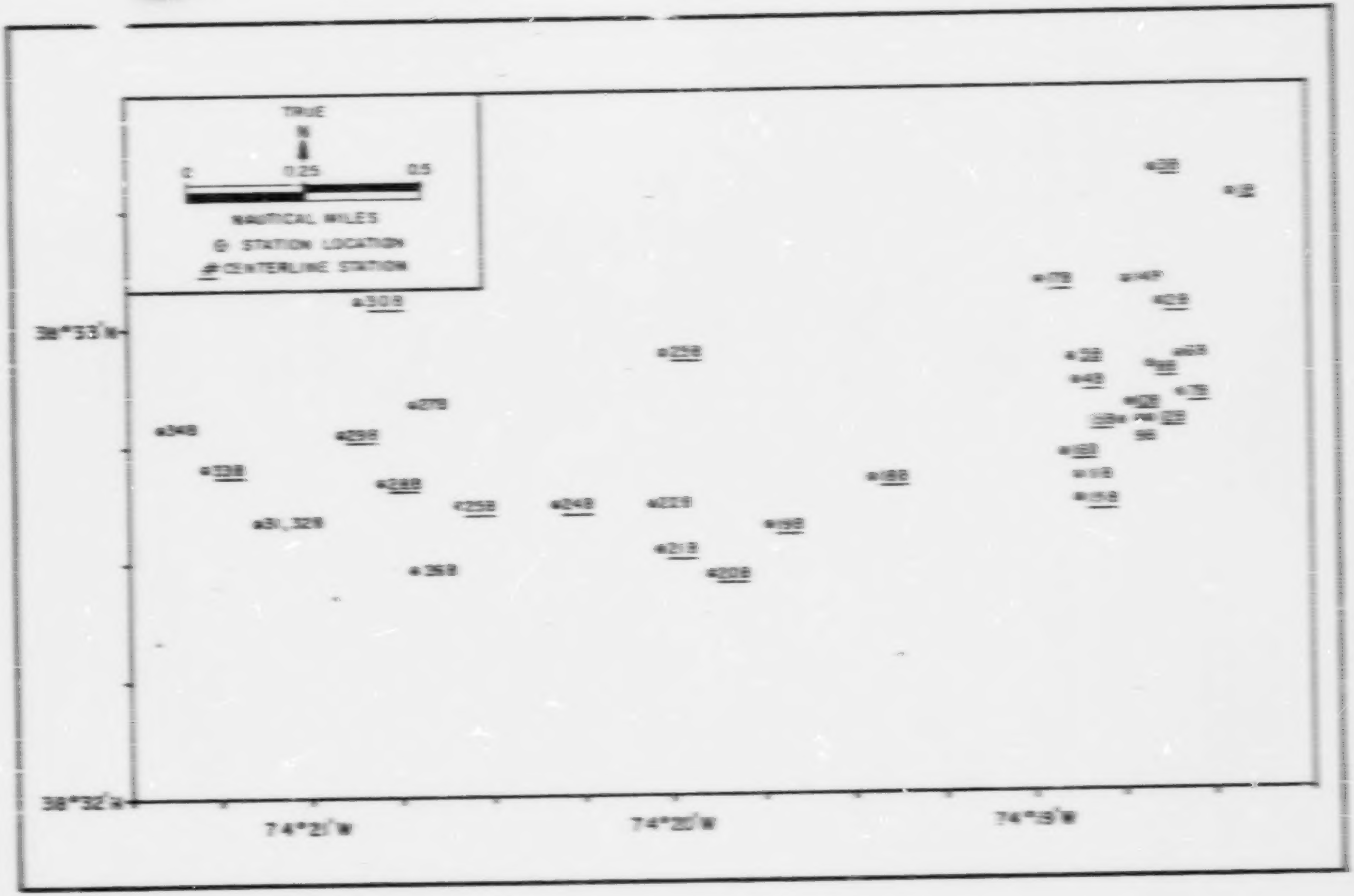
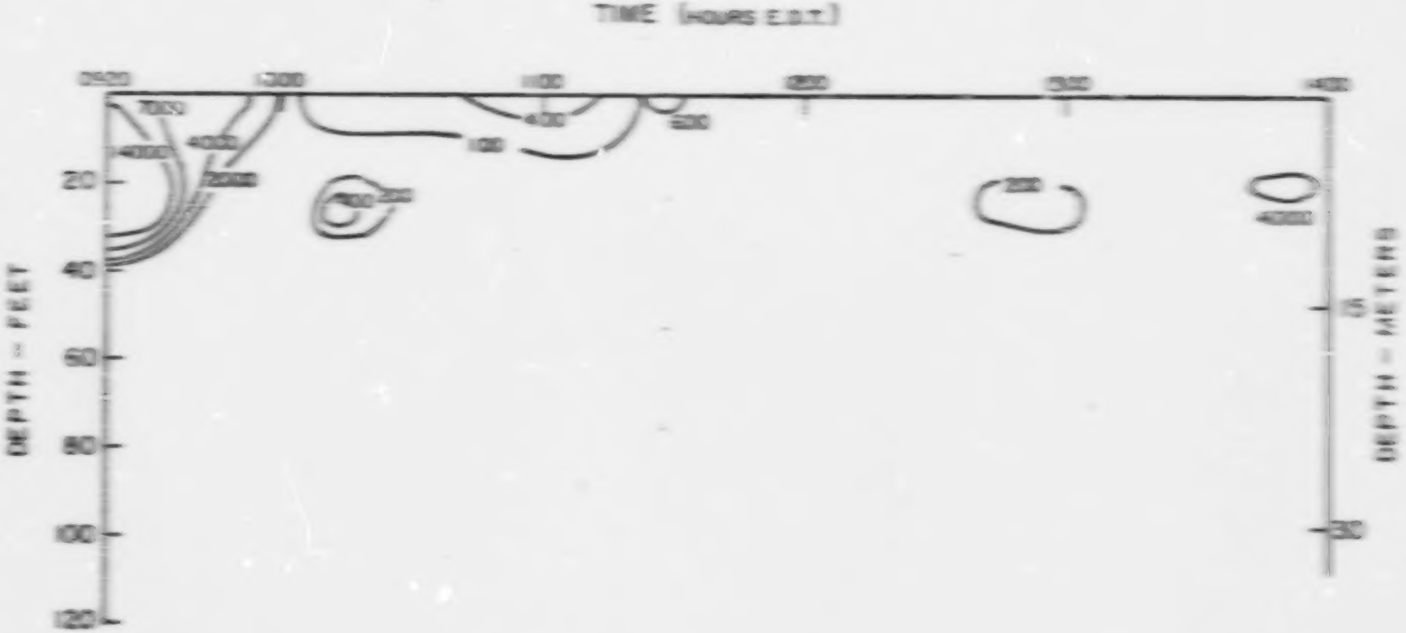

TRUE
N
0
0.25
0.5
NAUTICAL MILES
⊕ STATION LOCATION
# CENTERLINE STATION
38°33'N
38°32'N
74°21'W
74°20'W
74°19'W
30B
34B
33B
31,32B
29B
28B
27B
35B
24B
22B
21B
20B
19B
18B
17B
14B
3B
1B

FIGURE A-12

POSITIONS OF SAMPLING STATIONS

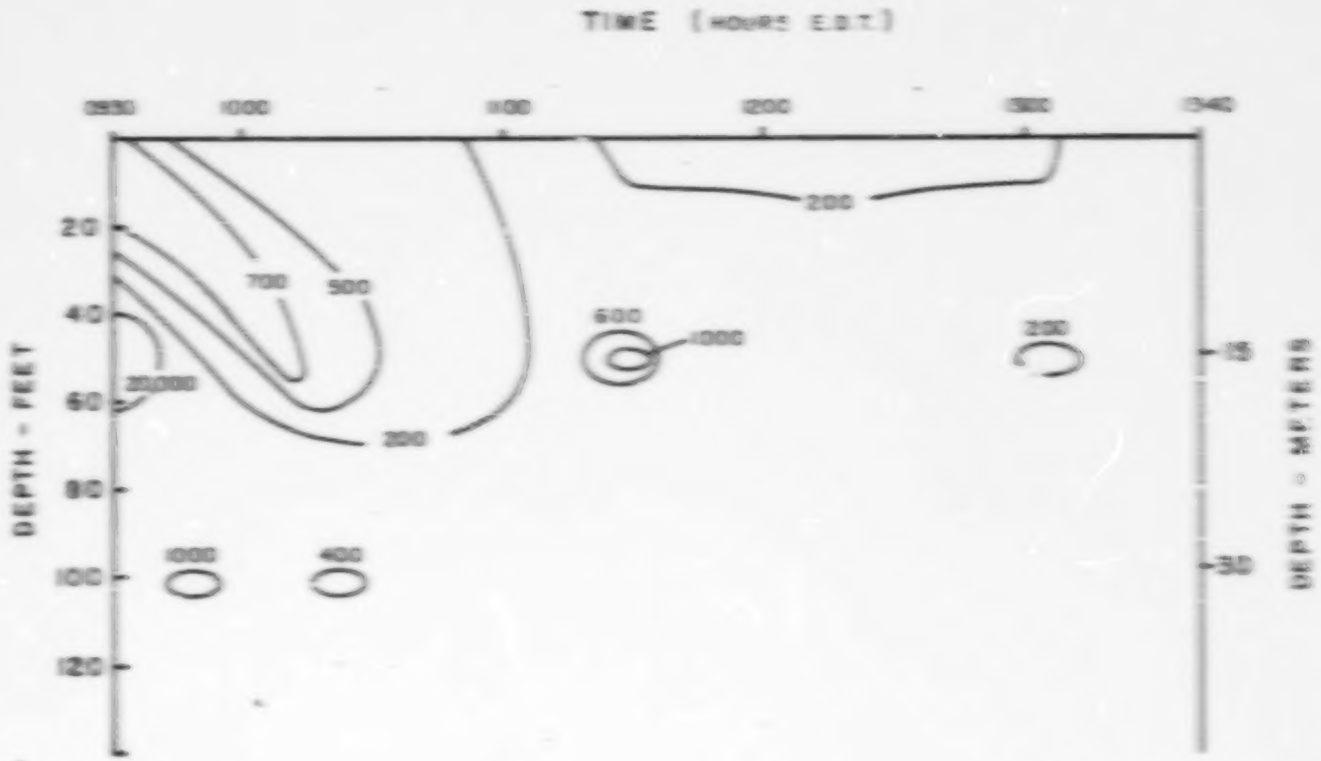
CRUISE K-03-70 - LINE B



RAW WASTE IRON CONCENTRATION=28.2 GM/L
BARGE SPEED=6 KNOTS

FIGURE A-13

TOTAL IRON (µG/L) ALONG CENTERLINE
CRUISE K-03-70 LINE A MAY 14, 1970



RAW WASTE IRON CONCENTRATION = 24.6 GM/L
BARGE SPEED = 3 KNOTS

FIGURE A-3A

TOTAL IRON (µG/L) ALONG CENTERLINE
CRUISE K-03-70 - LINE B - MAY 16, 1970

Background Study

On May 16, background stations 13, 11, and 2 were completed prior to the second barge run. Upon completion of Line B, background stations 8, 5, 4, and 6 were completed in that order. Station 5, the first station sampled in the disposal area, was reached about seven hours after the start of a barge discharge. Table A-5 summarizes the data collected. Considering the inherent limitations of the test procedures, no pronounced change was evident when these background data are compared to those obtained during the baseline cruise of May, 1969 (Cruise K-01-69). Dissolved oxygen, pH, alkalinity, nitrate, and total iron values were essentially the same as measured during Cruise K-01-69. Phosphates, after deviating in Cruise K-02-69, were again at the same levels of Cruise K-01-69. Kjeldahl nitrogens were still somewhat lower. The two control stations, Stations 2 and 8, were not significantly different from the three stations in the disposal area. This background data also indicate a relatively rapid return of the study area to background levels, considering the fact that the background stations were sampled so soon after a waste discharge.

The calculated light extinction coefficients are in Table A-6. Three of the four stations monitored coefficients of 0.03/ft for the entire depth, similar to that obtained during the previous surveys.

The coefficient for Station 6 increased about five-fold between the depths of 35 feet and 50 feet, with values of 0.03/ft above and below. This observation may have meant the waste may still have been present, at least to the point of affecting light penetration. An iron concentration of less than 100 µg/l was measured at the 50-foot depth. However, the break in light extinction occurred at this depth, and unfortunately no measurements of iron were taken between the 35 and 50 foot depths. The thermocline at this station was found to begin at about a 40-feet depth. The plume had a general westward movement during the dispersion on that day. Station 6, located at the western edge of the disposal area, was sampled approximately nine hours after the barge discharge began. However, fog was present during the light penetration study and may have caused some interference. Nevertheless, the light penetration results for Station 6 are evidence that iron floc may have been present.

TABLE A-5

DATA OF BACKGROUND STUDY

Cruise K-03-70 May 16, 1970
Research Vessel KYMA

Station	Depth (meters)	Temp. (°C)	Salinity (0/00)	pH	Alkalinity as $CaCO_3$ (mg/1)	D.O. (mg/1)	Total Iron (ug/1)	Total Phosphates (mg/1-PO_4)	Nitrate (mg/1-N)	Kjeldahl Nitrogen (mg/1-N)
2	1	11.2		8.10	119	5.4	13.	.013	.015	.01
(0722,*	15	8.9		7.98	122	9.4	----	.007	.013	.03
33.5+)	30	6.45		8.06	115	9.4	----	.158	.026	.05
4	1	10.8	32.505	8.15	120	9.4	27.	.065	.027	.03
(1650,*	15	9.6	32.505	8.16	120	9.8	5.	.025	.027	.01
43m+)	38	6.7	32.725	8.03	120	9.2	25.	.009	.018	.02
5	1	10.9	32.460	8.13	117	9.5	8.	.013	.013	.02
(1600,*	15	9.4	32.463	8.13	119	9.6	----	.005	.005	.06
45m+)	40	6.7	32.638	8.03	119	9.5	45.	.018	.018	.04
6	1	11.5	32.350	8.17	121	9.4	5.	.135	.135	.02
(1809,*	15	10.5	23.430	8.06	125	9.8	57.	.005	.005	.08
46m+)	38	6.65	32.650	8.04	119	9.7	----	.005	.005	.01
8	1	11.7	32.380	8.11	118	9.3	5.	.040	.040	.04
(1430,*	15	10.95	33.420	8.10	118	9.5	80.	.005	.005	.02
46m+)	45	6.60	32.690	8.06	117	9.8	8.	.043	.043	.01

*Eastern Daylight Savings Time.

+Total Depth.

TABLE A-5
(continued)

DATA OF BACKGROUND STUDY
Cruise K-03-76 May 16, 1976
Research Vessel KYMA

Station	Depth (meters)	Temp. (°C)	Salinity (0/00)	pH	Alkalinity as $CaCO_3$ (mg/l)	D.O. (mg/l)	Total Iron (µg/l)	Total Phosphates (mg/l-PO_4)	Nitrate (mg/l-N)	Kjeldahl Nitrogen (mg/l-N)
11	1	11.25	----	8.10	115	9.4	45	.005	.025	.06
(0415,*	15	11.00	----							
30M⁺)	30	9.60	----							
13	1	12.5		8.03	114	9.6	145	.005	.038	.02
(0255,*	18	11.7								
18M⁺)										

*Eastern Daylight Savings Time

⁺Total depth.

- -

TABLE A-6

SUBMARINE PHOTOMETER SUMMARY
OF
EXTINCTION COEFFICIENTS

Cruise K-03-76 May 16, 1976
Research Vessel KYMA

Station Number & Description	Extinction Coefficient (ft)
Background:	
#8 Depth = 150 ft.	0.03
#5 Depth = 148 ft.	0.03
#4 Depth = 141 ft.	0.03
#6 Depth = 148 ft.	0.03 (0 - 35 ft.) 0.15 (35 - 50 ft.) 0.03 (50 - 80 ft.)

- -

Summary

The total iron data of both lines show that the raw waste iron concentration was diluted by three orders of magnitude within the first twenty minutes after discharge. Alkalinity and pH values generally returned to background levels within one hour for Line A (6-knot barge speed) and three to four hours for Line B (3-knot). The data for Line A indicate that, under the condition of a relatively mild thermocline, the waste does not penetrate the vicinity of the thermocline under normal barging procedures.

The background study data indicate no substantial change in the water column of the study area that can be attributed to the barging operations.

The current data show the effects of a rotary tide with some directional shear and a general south-southwest drift trend over the depth of the water column. Current speeds averaged from 0.5 to 0.7 knots. A maximum net drift velocity of about 8.7 nautical miles per day was recorded.

CRUISE K-04-70, AUGUST 4-6, 1970

Description and Purpose

The purpose of this cruise was to study dispersion during a well-developed summer thermocline. The barge dispersed waste at about 6 knots on the morning of August 4, 1970. Background chemical and biological data were collected on August 5. A second 6-knot dispersion study was conducted on August 6. Continuous current meters operated at three depths at Station 5 during the entire period. Light penetration was measured during the background and the second dispersion studies.

Temperature and Current Data

A well developed stable thermocline extended from about 45 to 70-80 feet. Figure A-15 shows a typical temperature-salinity profile (Station 2, August 5, 1970).

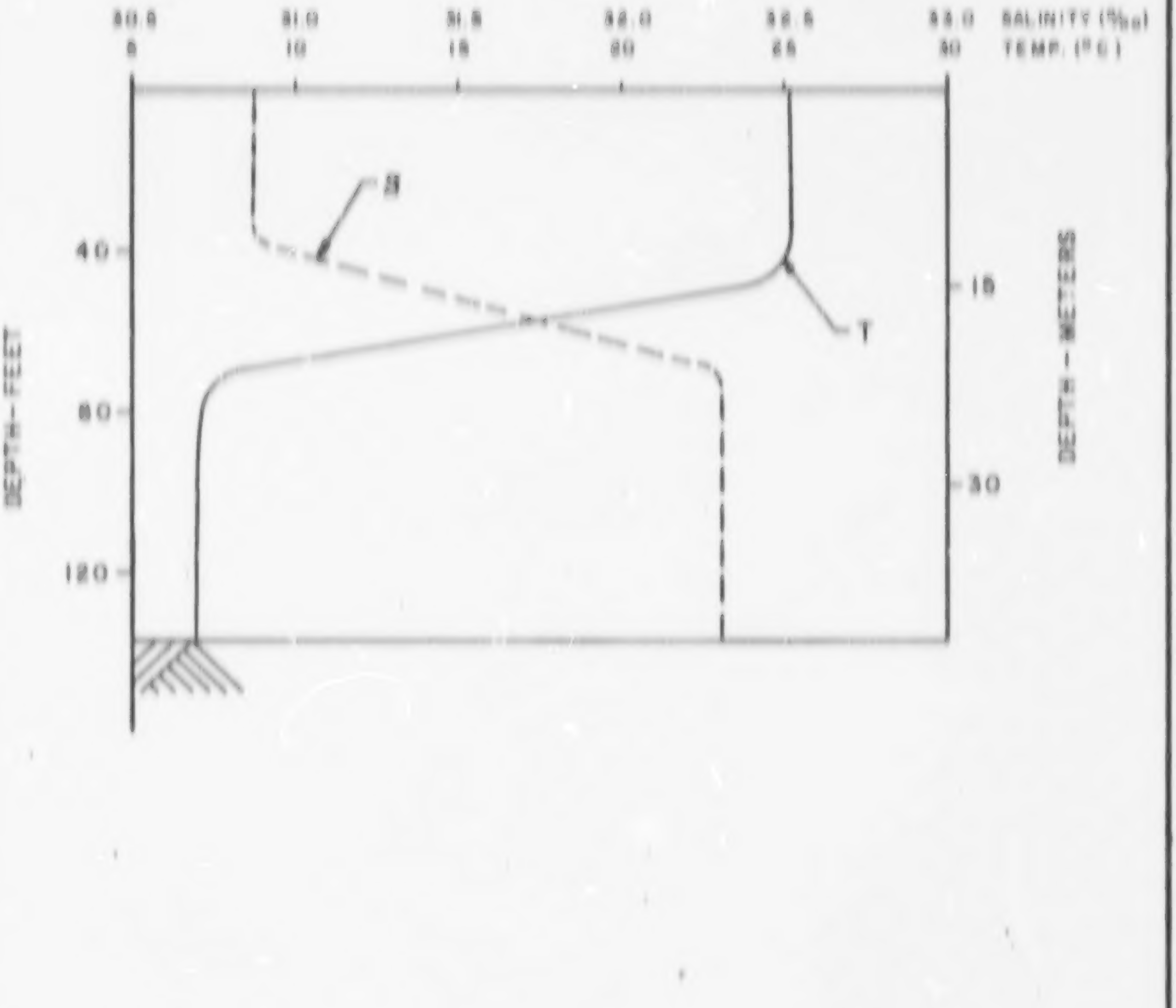


FIGURE A-15
VERTICAL TEMPERATURE & SALINITY PROFILES
CRUISE K-04-70 STATION #5 AUGUST 5, 1970

Continuous mode current meters at depths of about 25, 60, and 140 feet at Station 5 operated for about 55 hours, beginning at 0804, August 4. Figures A-16 through A-18 contain polar coordinate histogram plots of currents. Eulerian vector plots (Figure A-19) show a substantial directional shear. The 25-foot depth currents flowed in a north to northwest direction, those at mid-depth (60 feet, within the thermocline) were quite variable, but generally westerly, while currents at 140 feet moved generally to the south or southwest. The rotary tide was noted. Average current speeds ranged from about 0.4 knots at the bottom meter to 0.8 knots at the top. The maximum net spatial drift recorded (Figure A-19 top meter) was approximately 20 nautical miles for the 55-hour record, corresponding to a net drift velocity of about 0.36 knots (8.7 nautical miles per day) which occurred at the location of the top meter.

Dispersion Study

The Line A dispersion study was conducted under partly sunny skies with NW wind speeds of greater than 10 knots and relatively rough seas. Initial mechanical difficulties with a hydraulic winch immediately after barge discharge began prevented sample collection during the early dispersion stages.

The Line B study was conducted under clear skies with 3 to 5 feet swells from the southeast and NW winds at 7 to 9 knots.

The raw waste characteristics for both Lines were substantially different from previous surveys (Table 4). The iron content was about 60% higher. The observed distinguishable straw color of the waste plume indicated a stronger waste than on previous surveys.

Twenty-four stations were sampled for Line A and 30 for B. Station positions are in Figure A-20. For Line A, the centerline station positions indicated a surface plume drift to the northwest. The distance covered during the approximate four hours sampling period was about 2.1 nautical miles. For Line B, the centerline stations indicated essentially no net drift. The last centerline station was about 1.1 nautical miles from the first. At about 6 hours after discharge, the Line B waste plume was again sighted at the same location as station 26B, showing the lack of net movement of the waste plume during that period.

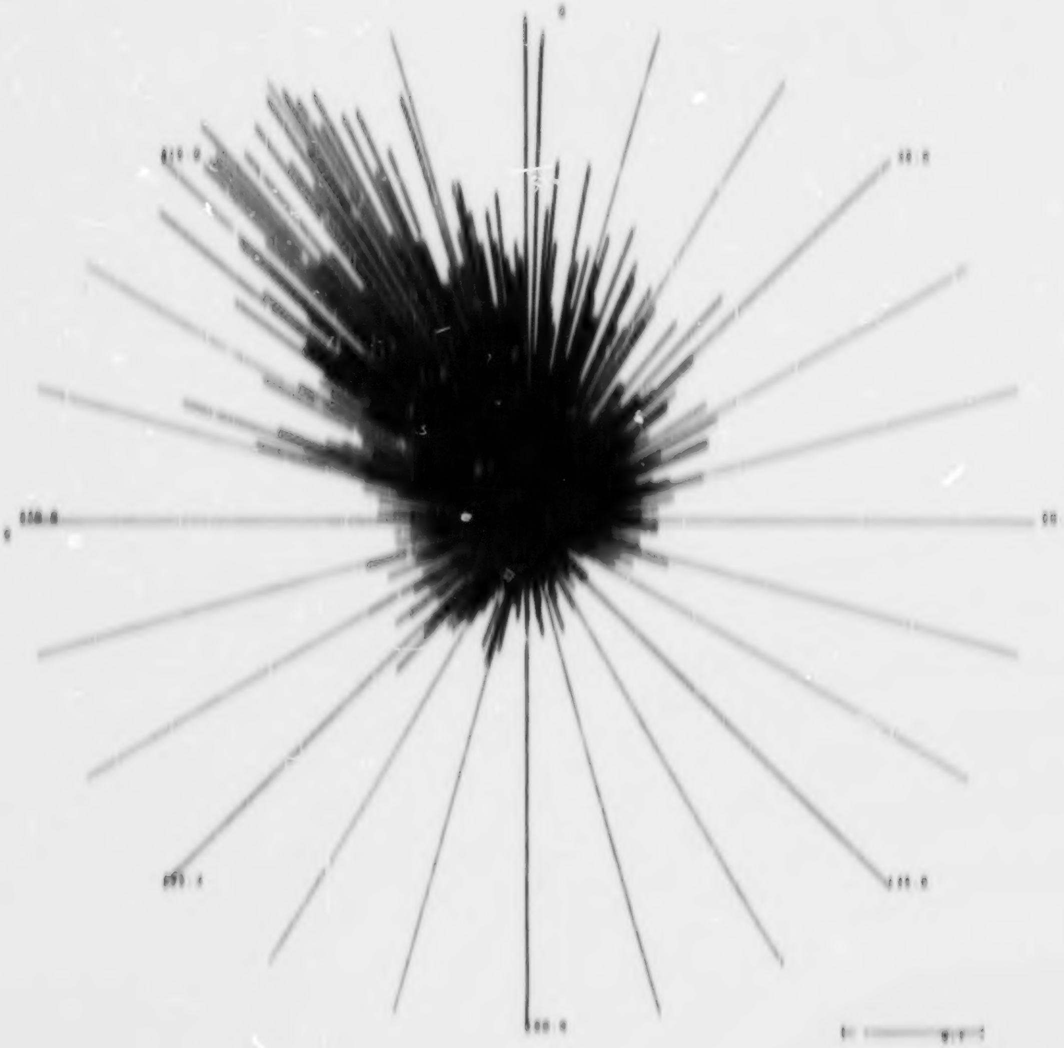


FIGURE A-16
CONTINUOUS CURRENT METER RESULTS
TOP METER - DEPTH = 25 FEET
CRUISE K-04-70 AUGUST 4-6, 1970

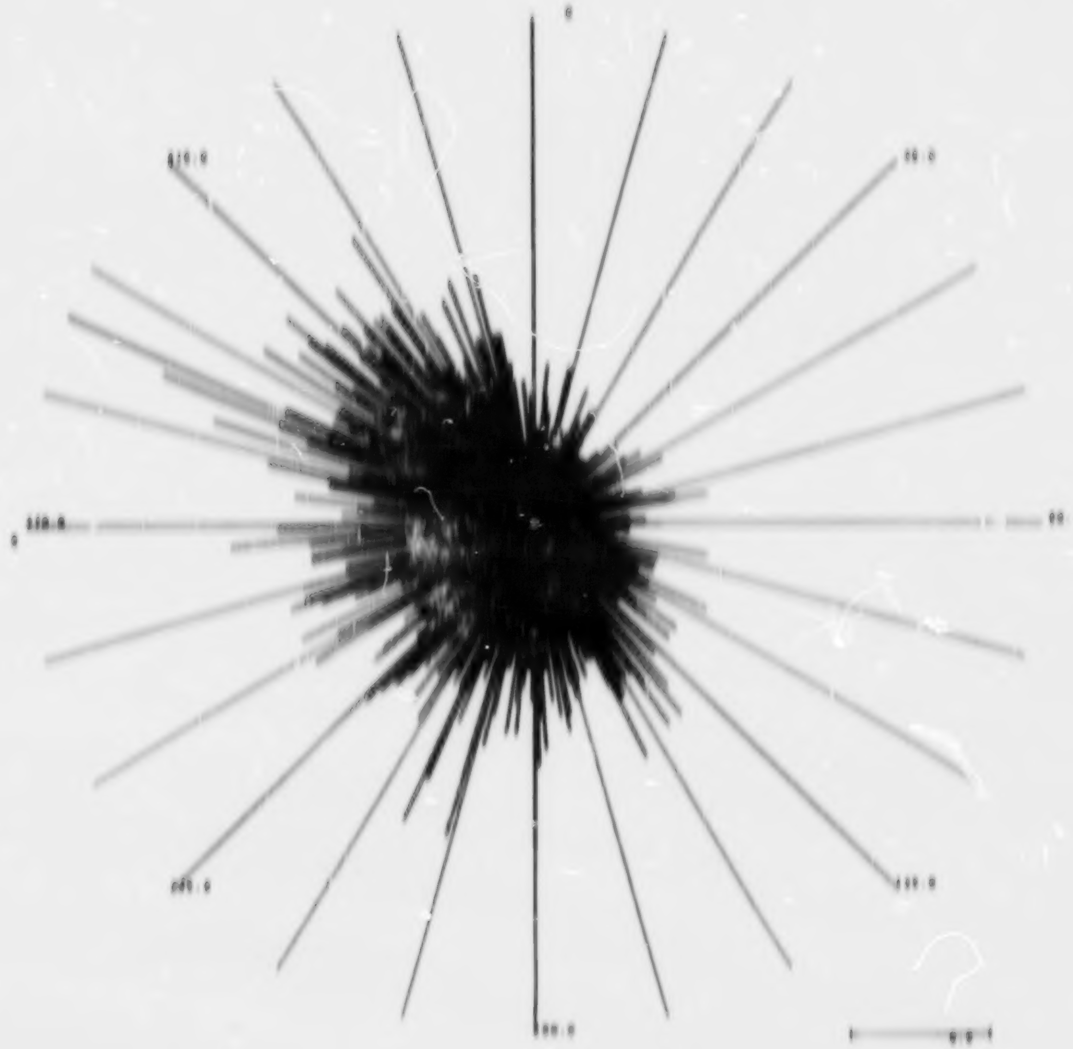


FIGURE A-17
CONTINUOUS CURRENT METER RESULTS
MIDDLE METER - DEPTH ≈ 60 FEET
CRUISE K-04-70 AUGUST 4-6, 1970

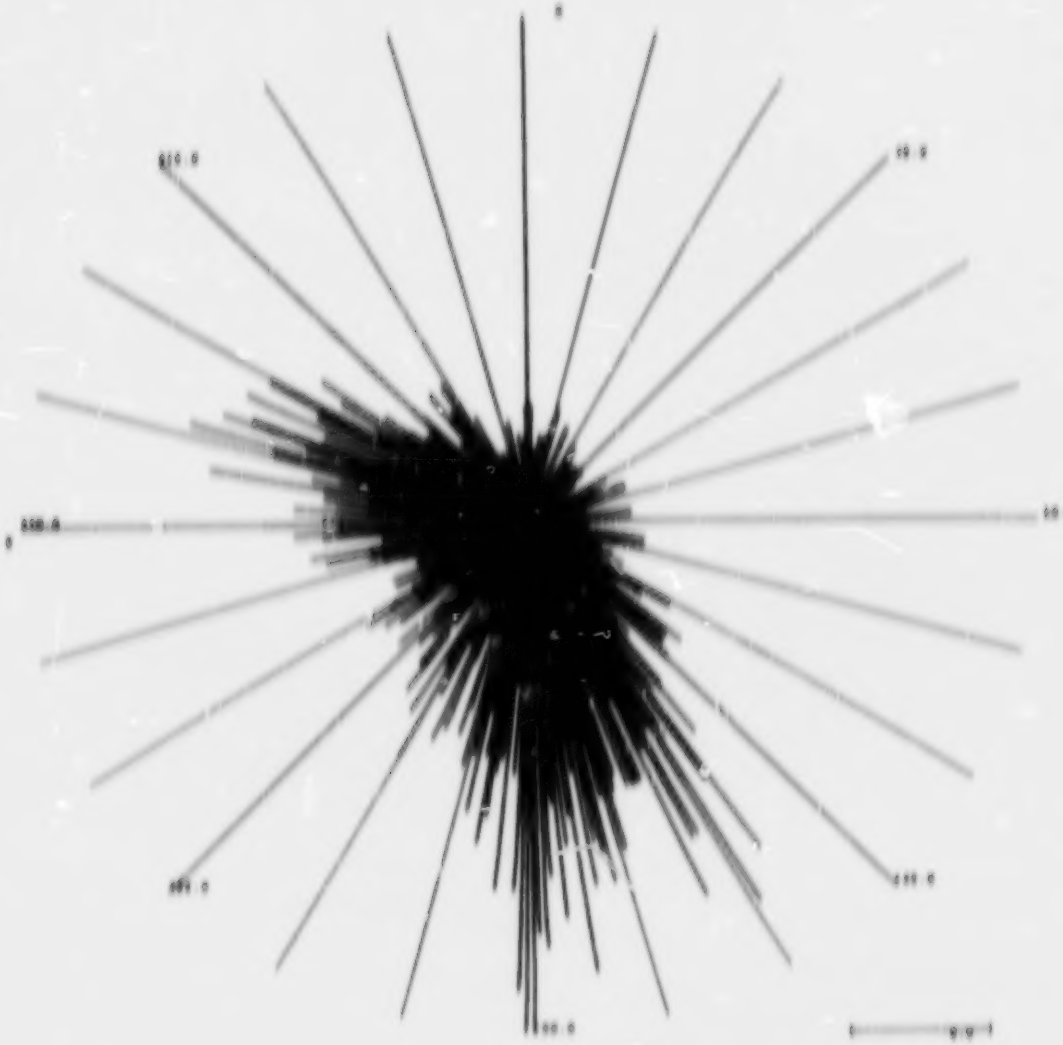


FIGURE A-18
CONTINUOUS CURRENT METER RESULTS
BOTTOM METER - DEPTH ≈ 140 FEET
CRUISE K-04-70 AUGUST 4-6, 1970

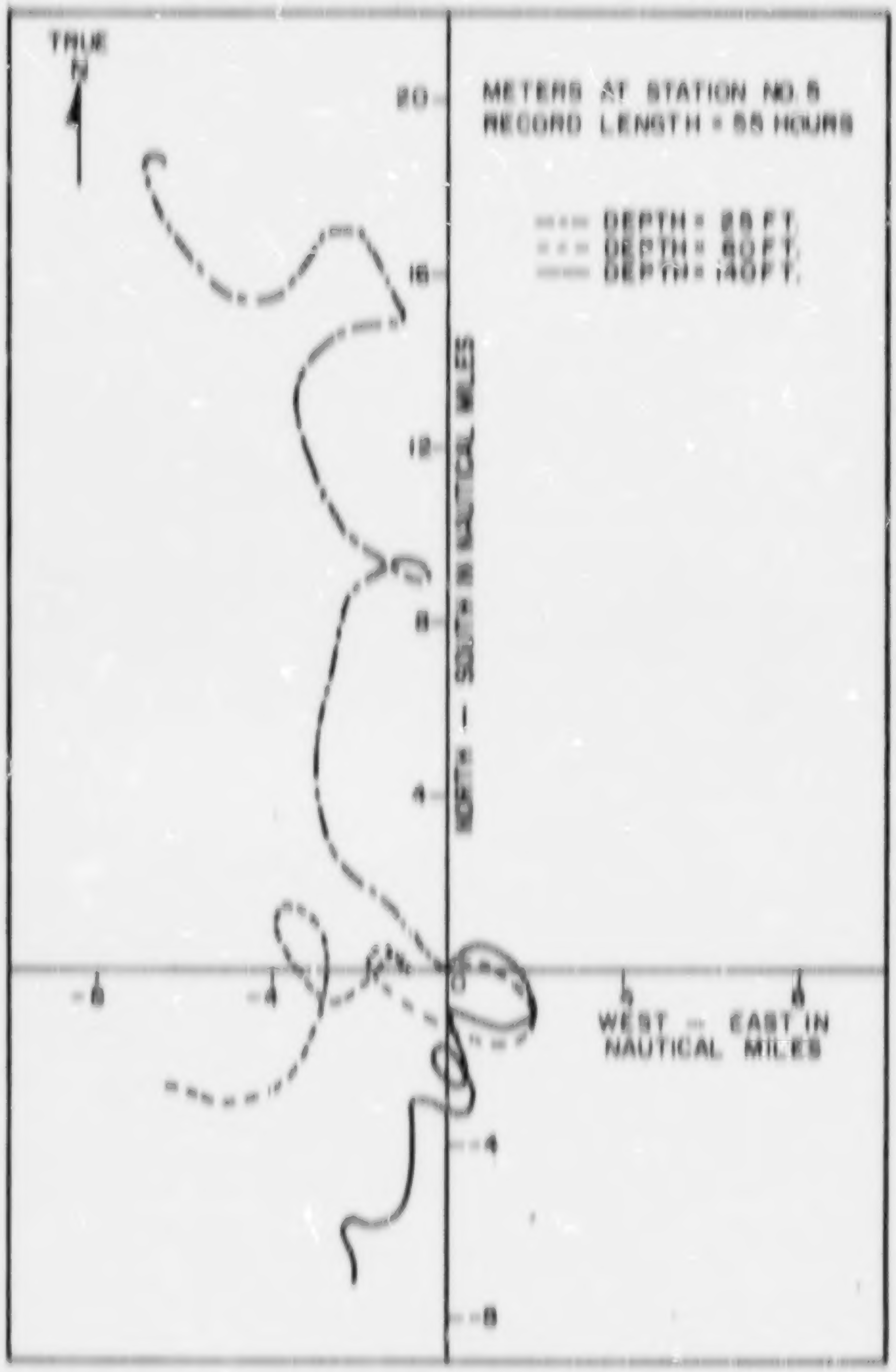


FIGURE A-19
CONTINUOUS CURRENT METER RESULTS
CRUISE K-04-70 AUGUST 4-6, 1970

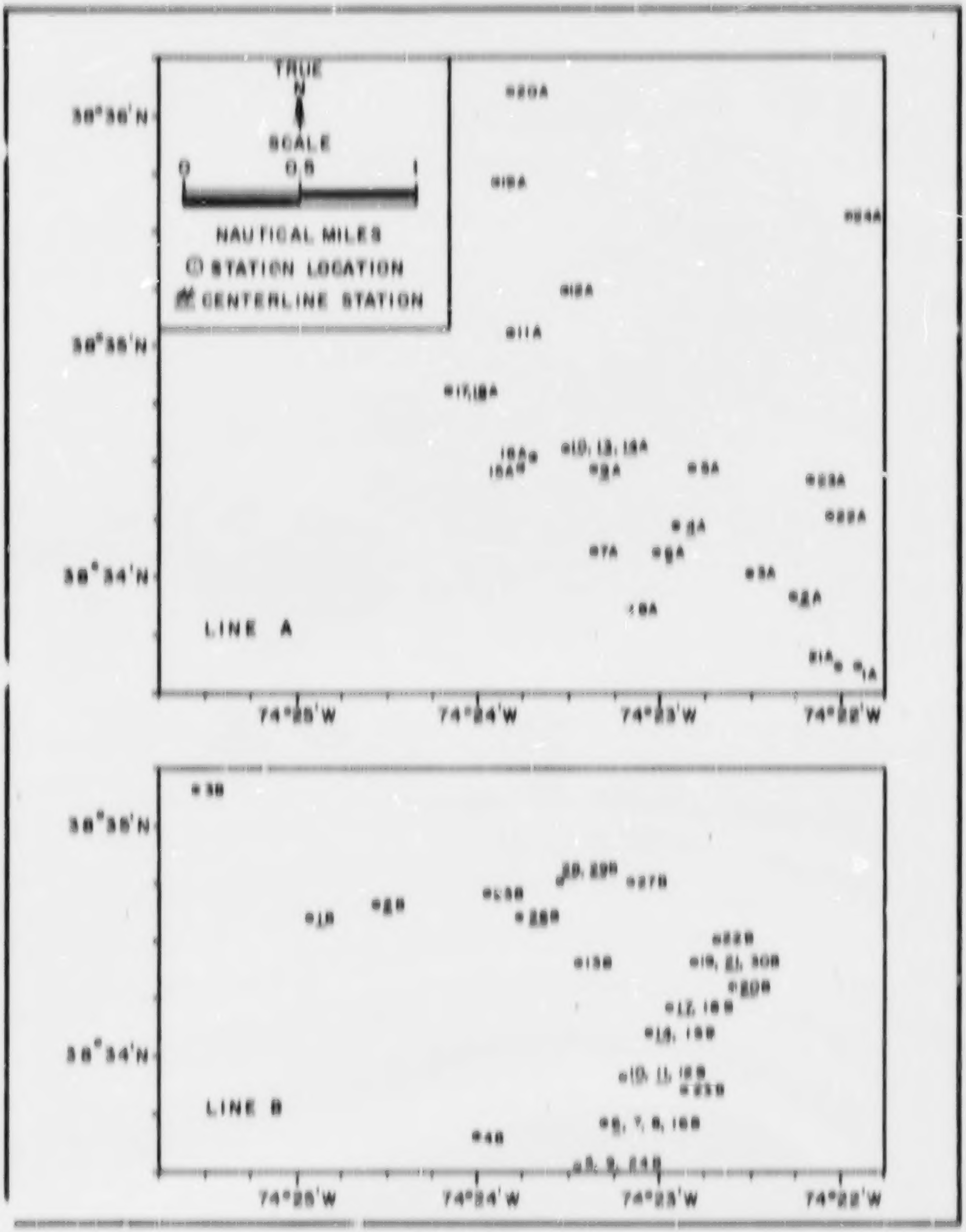

TRUE
N
SCALE
0
0.5
1
NAUTICAL MILES
STATION LOCATION
CENTERLINE STATION
38°36'N
38°35'N
38°34'N
LINE A
20A
19A
24A
12A
11A
17,18A
10, 13, 16A
15A
14A
9A
5A
23A
22A
4A
7A
6A
3A
2A
8A
21A
1A
74°25'W
74°24'W
74°23'W
74°22'W
3B
38°35'N
38°34'N
LINE B
1B
2B
13B
26B
25, 29B
27B
22B
15B
19, 21, 30B
20B
17, 18B
14, 19B
10, 11, 12B
23B
6, 7, 8, 16B
4B
5, 9, 24B
74°25'W
74°24'W
74°23'W
74°22'W

FIGURE A-20
POSITION OF SAMPLING STATIONS
CRUISE K-04-70

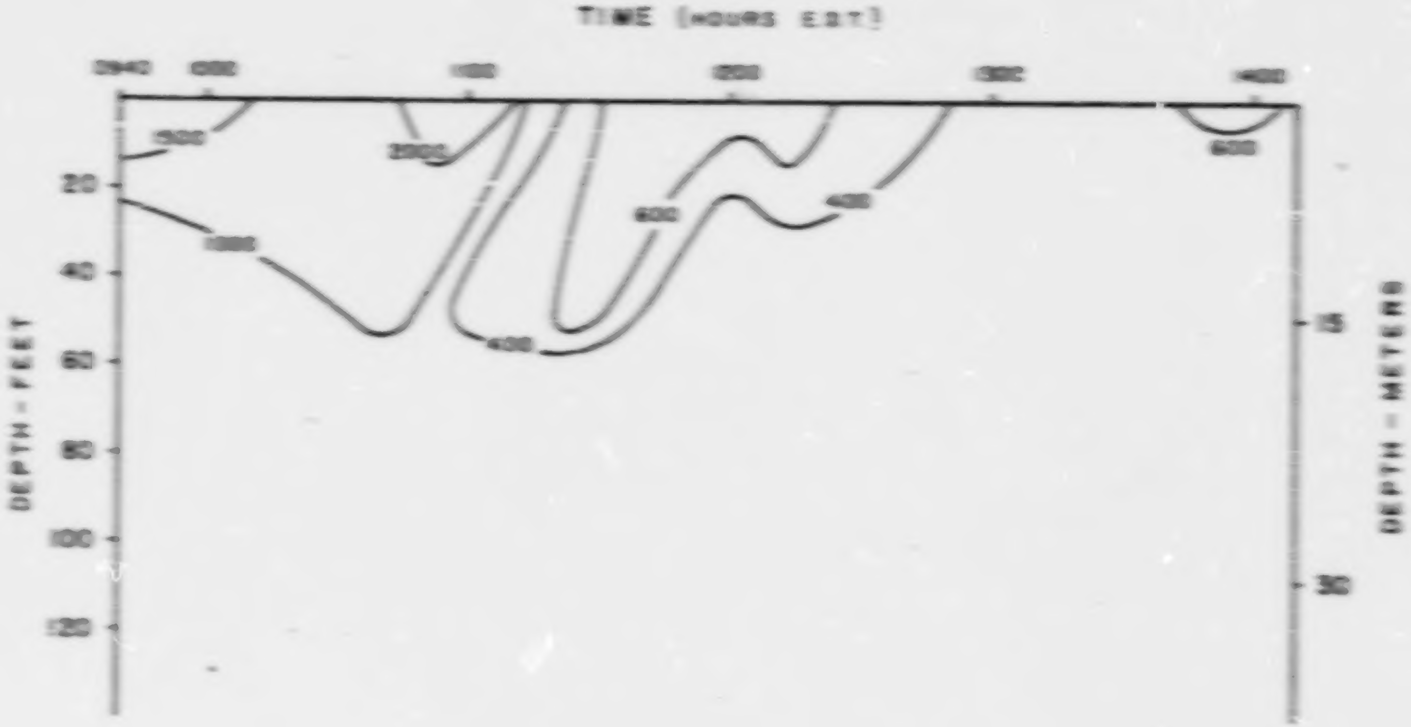
Figures A-21 and A-22 show the iron concentrations along the assumed centerline as a function of time and depth for Lines A and B, respectively. For Line A, iron concentrations measured at the 50-foot depth south of the visual plume centerline were substantially higher than those measured along the surface visual centerline. This was probably caused by the current directional shear shown by the recorded currents. Since these higher values are more indicative of the actual centerline of the waste field at the 50-foot depth, they have been incorporated into Figure A-22. However, for Line A, the data indicate current directional shear was minimal.

As noted, mechanical difficulties permitted only one station of Line A to be sampled within the first hour after discharge. Consequently, Figure A-21 contains iron concentrations after the first hour of initial discharge. A dilution by four orders of magnitude of the raw waste iron concentration had already occurred. This is in contrast to Figure A-22, where values as high as 16 mg/l Fe were measured. This concentration corresponds to a dilution of the raw waste by about 3-1/2 orders of magnitude in the first 15 minutes after discharge for Line B. Reduction by about four orders of magnitude was accomplished within about 2 hours after discharge. The data of both Lines also demonstrated that the waste did not penetrate below the vicinity of the thermocline.

Although the raw waste characteristics for both Lines were similar, higher iron concentrations remained in the water column for longer periods for Line B. At about four hours after discharge, iron was about 5 mg/l at the 50-foot level for Line B. This contrasted with Line A where, at the end of four hours, the concentrations were less than 0.7 mg/l. The pH and alkalinity measurements concur with these results. For Line B, the lowest initial pH and alkalinity measurements were 6.1 and 59 mg/l as $CaCO_3$, respectively, with a pH of 7.1 and alkalinity of 95 mg/l after four hours. For Line A, both pH and alkalinity were already near background levels at the first station, sampled about one hour after discharge.

Light Penetration

Light extinction coefficients are summarized in Table A-7. During the background study, the coefficients were similar to those measured during previous studies. However, in the visual centerline of the Line B plume, coefficients averaged about 0.1/ft. This is about three times the average coefficient measured during the background study. This shows a change in the depth of 1% of surface light from about 150 feet under



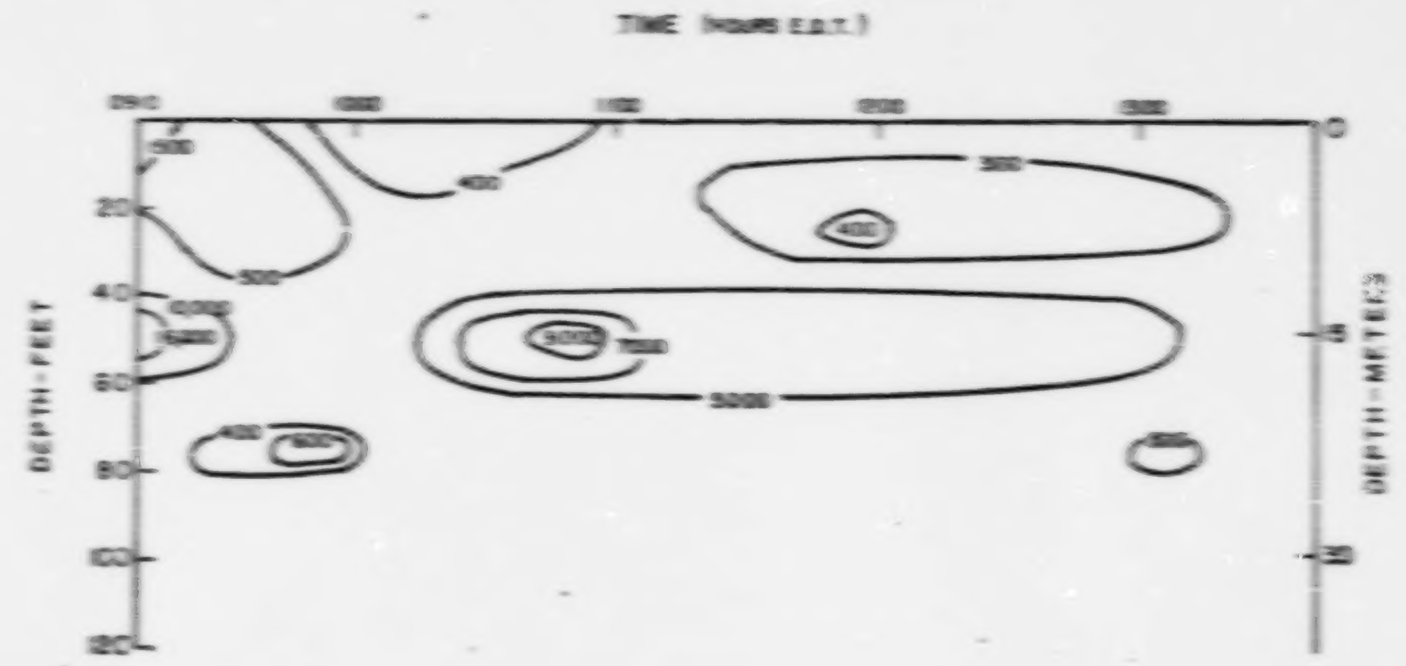
RAW WASTE IRON CONCENTRATION = 45.6 GM/L

BARGE SPEED = 6 KNOTS

FIGURE A-21

TOTAL IRON (µG/L) ALONG CENTERLINE

CRUISE K-04-70 LINE A AUGUST 4, 1970



RAW WASTE IRON CONCENTRATION=44,6 GM/L
BARGE SPEED=6 KNOTS

FIGURE A-22

TOTAL IRON (µG/L) ALONG CENTERLINE
CRUISE K-04-70 LINE B AUGUST 6, 1970

TABLE A-7

SUBMARINE PHOTOMETER SUMMARY
OF
EXTINCTION COEFFICIENTS

Cruise K-04-70 August 5-6, 1970
Research Vessel KYMA

Station Number and Description	Extinction Coefficient (ft)
Background:	
#2 Depth = 137 feet	.03
#4 Depth = 155 feet	Interference (clouds)
#5 Depth = 135 feet	.03
#6 Depth = 128 feet	.04
#8 Depth = 126 feet	.03
During Waste Dispersion	
℄ of plume at 10:15 - Water color - light straw	0.10 (0 - 40 feet)
℄ of plume at 10:20 - Water color - brownish green	0.12 (0 - 40 feet)
Marker Buoy at 11:04 south of visual ℄	0.03 (0 - 40 feet) 33% decrease (40-50 ft) 0.06 (50 - 70 feet)
Marker buoy at 11:08 south of visual ℄	0.03 (0 - 40 feet) 30% decrease 40-50 ft) 0.06 (50 - 70 feet)
℄ of plume at 11:40 - Water color - lt. green or brownish green	0.11 (0 - 40 feet)
℄ of plume at 13:28	0.10 (0 - 40 feet)

normal conditions to about 45 feet in the centerline of the spreading plume. The practical limit of the standard photometer used is about 1% of surface light, so measurements in the visual centerline of the waste plume were limited to depths above the thermocline. Thus, these results are inconclusive in verifying the accumulation of waste in the vicinity of the thermocline. It is interesting to note that substantial effects on light penetration persisted in the visual centerline of the plume, although maximum iron concentrations had decreased to about 200 µg/l-Fe over the depth of the water column measured for light penetration. This indicates that light is significantly affected even by dilute ferric floc.

The results obtained at the marker buoy station are also of special interest. Light studies were conducted at station 16B when the visual centerline of the plume was about 0.6 miles to the north. The light extinction from the surface to about 40 feet was similar to that obtained under normal background conditions. However, a distinct 30% decrease in light penetration occurred between the 40 and 50 feet. The coefficients below 50 feet were about 0.06/ft with 1% of surface light measured at about 70 feet. It is postulated that this resulted from shearing of the waste field by the directional current shear in the vicinity of the thermocline. Iron was measured at the marker buoy station just prior to the light penetration studies. Although the iron content at the 50-foot depth was less than 10 µg/l, a value of 230 µg/l was measured at 75 feet. A movement of the waste in a "finger-like" configuration is postulated to explain the apparent contradiction of the low iron value at the 50-foot depth. Iron at the surface and 25-feet depth were less than 12 µg/l-Fe which concurs with the light penetration data above the thermocline.

Background Study

Background stations 13, 11, 2, 4, 8, 5, and 6 were sampled in that order on August 5, 1970. Skies were generally sunny to partly sunny, with light and variable winds, and a slight swell.

Table A-8 summarizes the chemical data collected. Dissolved oxygen was near saturation in the surface water and slightly below at the 100-foot depth. Iron concentrations were below detectable limits of the test. Total phosphates were similar to those measured during Cruises K-01-69 and K-03-70. Kjeldahl nitrogen concentrations were similar to those measured during Cruise K-01-69. The two control stations were not significantly different from the three stations in the disposal area.

TABLE A-8

DATA OF BACKGROUND STUDY
Cruise K-04-70, Aug. 5, 1970
Research Vessel KYMA

Station	Depth (meters)	Temp. (°C)	Salinity (0/00)	Chlorides (0/00)	pH	Alkalinity as CaCO$_3$ (mg/l)	D.O. (mg/l)	Total Iron (μg/l)	Total Phosphates (mg/l-PO$_4$)	Kjeldahl Nitrogen (mg/l-N)
2	1	25.2	30.920	17,550	8.09	113.5	7.0	0	0.023	.20
(0830,*	15	23.5	31.367	17,650	7.99	117.6	7.6	0	0.020	.02
37M^{+})	30	7.0	32.306	18,200	7.84	120.5	8.6	0	0.125	.03
4	1	25.4	30.805	17,400	8.09	113.7	7.1	0	0.025	.02
(1005,*	15	23.5	31.220	17,700	8.07	114.5	7.6	0	0.025	.02
47M^{+})	35	6.6	32.307	17,900	7.90	120.5	8.2	0	0.073	.03
5	1	25.6	31.176	17,700	8.12	117.5	7.0	0	0.010	.015
(1455,*	15	20.0	31.677	17,900	8.03	118.5	8.0	0	0.055	.02
42M^{+})	30	6.8	32.304	18,200	7.86	120.0	8.3	0	0.100	.03
6	1	25.5	31.375	17,800	8.06	117.5	8.6	0	0.200	.011
(1620,*	15	13.6	31.753	18,000	7.90	117.3	8.5	0	0.075	.020
39M^{+})	30	6.8	32.232	18,450	7.84	121.0		0	0.110	
8	1	25.4	31.078	17,500	8.06	114.5	7.0	0	0.043	.03
(1305,*	15	17.5	31.796	18,100	8.01	119.5	8.5	0	0.043	.03
38M^{+})	30	7.3	32.425	18,550	7.82	121.5	8.4	0	0.090	.02

*Eastern Daylight Savings Time

$^{+}$Total Depth.

TABLE A-8
(continued)

DATA OF BACKGROUND STUDY
Cruise K-04-70, Aug. 5, 1970
Research Vessel KYMA

Station	Depth (meters)	Temp. (°C)	Salinity (0/00)	Chlorides (0/00)	pH	Alkalinity as $CaCO_3$ (mg/l)	D.O. (mg/l)	Total Iron (µg/l)	Total Phosphates (mg/l-PO_4)	Kjeldahl Nitrogen (mg/l-N)
11 (0645*)	1	23.3		17,650	8.09	117.0	6.9	3.	0.060	.21
13 (0445*)	1	19.0		17,200	7.86	114.5	8.1	0	0.108	.02

*Eastern Daylight Savings Time

Summary

Initial dilution of the raw waste iron concentration by about four orders of magnitude occurred within the first two hours after discharge for both Lines. A dilution by more than three orders of magnitude was observed for Line B within 15 minutes after discharge.

The inability of the waste to penetrate the strong thermocline was demonstrated. Higher iron concentrations levels persisted for longer periods after discharge than was generally observed in previous dispersion studies, especially for Line B. Line B was also the only dispersion study where pH and alkalinity still substantially deviated from background levels at the end of four hours. Thus, although an intense thermocline minimizes the probability of waste settling to the ocean floor, it maximizes the time necessary for the water column to return to background.

Light penetration in the plume's visual centerline was decreased by about a factor of three over that measured elsewhere. Significant effects on light penetration were observed in waters where iron concentrations were near background levels.

The background study data indicate no substantial change in the chemical nature of the water column of the study area attributable to the barging operation.

The current data indicate a rotary field with a pronounced directional shear over the depth of the water column. Northwest surface currents show that a reversal in surface drift sometimes occurs during the late spring and summer period, since a southwest surface drift was observed in the previous May survey (Cruise K-03-70) of that year. Bottom waters generally drifted to the southwest. Current speeds averaged from 0.4 to 0.8 knots over the depth of the water column. A maximum net drift of about 8.7 nautical miles per day was recorded at the surface.

CRUISE K-05-71, MARCH 2-10, 1971

Description and Purpose

On March 2, 1971, a study was conducted of waste dispersion under winter conditions of an isothermal regime. Because of severe weather conditions (wind greater than 50 knots) the following day, a background chemical and biological study was delayed until March 10. Current recorders were not installed because of possible difficulties foreseen in retrieving the devices during a winter period.

Temperature measurements confirmed the expected vertically homogeneous temperature regime (Figure A-23).

Dispersion Study

Dispersion was studied at a barge speed of 6 knots in calm seas with overcast skies and some light precipitation. Wind speeds were generally less than 10 knots.

The waste iron concentration (Table 4) was the lowest of any other dispersion study and the plume did not have as distinguishable a color as in previous surveys. It remained pale green during the entire sampling period. The overcast may have been a contributing factor.

Figure A-24 shows the positions of the 42 sampling stations. Only Loran coordinates were available during this cruise. The centerline stations indicate no net current drift, the last station being only about one mile from the first.

Figure A-25 shows iron concentrations along the assumed centerline of the waste plume as a function of time and depth. Directional shear at the bottom was indicated by two iron concentrations in excess of 500 µg/l at the 100-foot depth at the apparent southern edge of the visual waste plume toward the end of the sampling period. Figure A-25 shows these since they are more indicative of the center of the waste field at that depth.

The plume remained relatively narrow (approximately 60 feet, equal to the length of Kyma) for about an hour after initial discharge. Difficulty in distinguishing the edges of the plume made sampling rather difficult. Iron was very low (less than 10 µg/l) in the initial centerline at the 25-foot depth. Procedural delays in taking the 25-foot samples coupled with the above conditions may have resulted in the Kyma drifting out of the plume during sampling. Therefore, the 25-foot centerline iron values are omitted from Figure A-25.

Unlike previous studies, iron concentrations were relatively low. Only seven samples showed concentrations above 500 µg/l. The maximum initial value was 3,400 µg/l corresponding to a

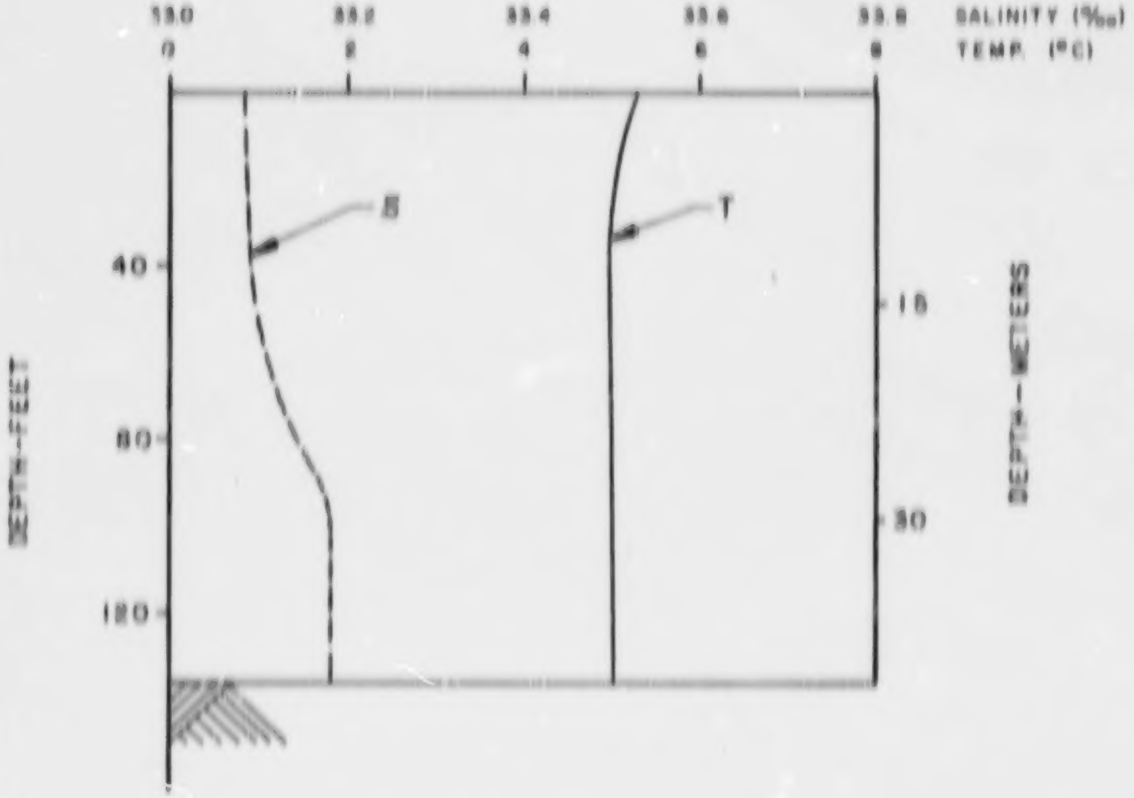


FIGURE A-23
VERTICAL TEMPERATURE & SALINITY PROFILES
CRUISE K-05-71 STATION #6 MARCH 10, 1971

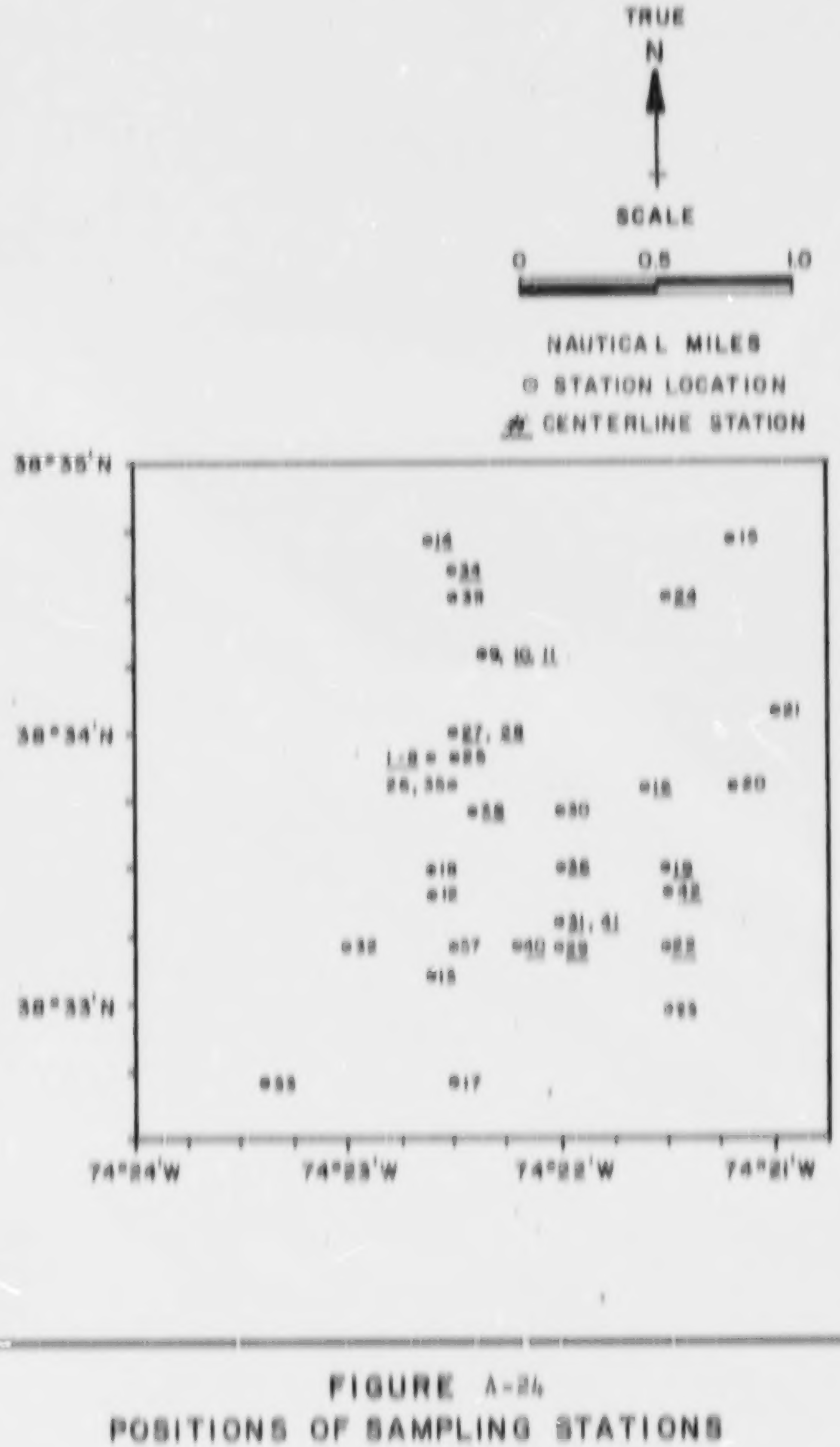
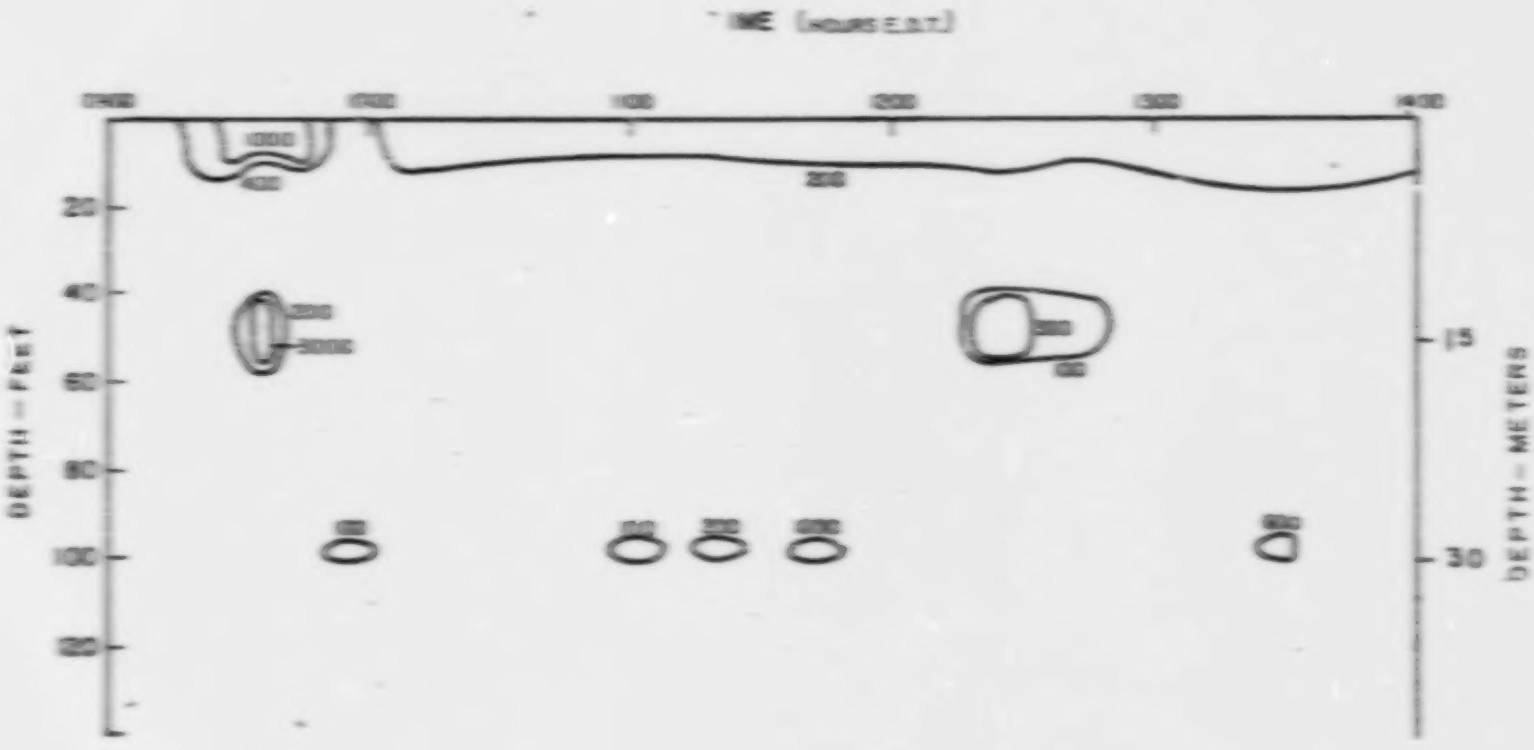

TRUE
N
SCALE
0
0.5
1.0
NAUTICAL MILES
⊙ STATION LOCATION
# CENTERLINE STATION
38°35'N
38°34'N
38°33'N
74°24'W
74°23'W
74°22'W
74°21'W
⊙14
⊙15
⊙34
⊙39
⊙24
⊙9, 10, 11
⊙21
⊙27, 28
1-8 ⊙ ⊙25
26, 35⊙
⊙16
⊙20
⊙38
⊙30
⊙18
⊙36
⊙19
⊙12
⊙42
⊙31, 41
⊙32
⊙37
⊙40
⊙29
⊙22
⊙13
⊙23
⊙33
⊙17

FIGURE A-24
POSITIONS OF SAMPLING STATIONS
CRUISE K-05-71 MARCH 2, 1971



RAW WASTE IRON CONCENTRATION=24.6 GM/L
BARGE SPEED=6 KNOTS

FIGURE A-25

TOTAL IRON (µG/L) ALONG CENTERLINE
CRUISE K-05-71 MARCH-2, 1971

raw waste iron dilution of about four orders of magnitude within the first 30 minutes. At the end five hours, iron concentrations over the depth of the water column were essentially at background levels. During previous studies conducted under normal barging procedures, concentrations as high as 16 mg/l were measured in the plume's centerline. The lower values measured during this study may have been caused by the increased mixing volume available because of the absence of a thermocline. Furthermore, the majority of iron concentrations measured were less than 100 μg/l except for the top centerline samples which averaged about 240 μg/l. These results are generally confirmed by the pH and alkalinity data obtained. Lowest pH and alkalinity values of 7.1 and 91 mg/l as $CaCO_3$, respectively, were recorded about 30 minutes after discharge at the 50-foot depth and correspond to the maximum iron concentrations observed. All other pH and alkalinity measurements were above 7.5 and 110 mg/l as $CaCO_3$, respectively.

Background Study

Background stations 13, 11, 2, 4, 8, 5, and 6 were sampled in that order on March 10, 1971. Skies were generally clear except for overcasts at the last two stations. Seas and winds were generally calm.

Table A-9 summarizes the water column chemical data. Dissolved oxygen was at or near saturation at all depths. Iron concentrations were below the sensitivity of the analytical test, during Cruise K-04-70. Total nitrogen and phosphates were relatively high compared to previous background surveys. The two control stations were not significantly different from the three stations in the disposal area.

Calculated light penetration extinction coefficients (Table A-10) are somewhat higher than those for previous background studies which had typical values of 0.03/ft. Higher turbidity due to the excessive winds and associated turbulent oceanic conditions prevalent for eight days prior to the measurements may have been the cause.

Summary

Unlike previous dispersion studies conducted under normal barging procedures, iron concentrations were above background

TABLE A-9

DATA OF BACKGROUND STUDY
Cruise K-05-71, Mar. 10, 1971
Research Vessel KYMA

Station	Depth (meters)	Temp. (°C)	Salinity (0/00)	Chlorides (0/00)	pH	Alkalinity as $CaCO_3$ (mg/1)	D.O. (mg/1)	Total Iron (µg/1)	Total Phosphates (mg/1-PO_4)	Total Nitrogen (mg/1-N)
2	1	5.0	33.140	20.700	7.9	116.0	10.5	3.	0.08	1.05
(0715,*	15	5.0	33.147	20.450	8.0	116.7	10.2	8.	0.16	1.05
32m$^+$)	30	5.0	33.148	19.200	8.0	119.5	10.4	6.	0.75	1.14
4	1	6.1	33.415	20.000	8.0	120.5	10.3	3.	0.30	1.10
(1015,*	15	5.6	33.404	20.900	8.0	117.9	10.3	4.	0.14	1.08
40m$^+$)	30	6.1	33.540	20.800	8.0	120.5	9.9	4.	0.22	1.14
5	1	5.5	33.236	20.300	8.0	117.2	10.7	4.	0.10	1.08
(1610,*	15	5.5	33.229	20.750	8.0	120.0	10.3	6.	0.37	1.02
35m$^+$)	30	5.4	33.452	20.750	8.0	117.3	9.8	4.	0.12	1.00
6	1	5.3	33.072	18.550	8.0	117.3	10.6	4.	0.13	0.88
(1810,*	15	5.0	33.090	20.450	8.0	117.0	10.4	4.	0.13	0.88
40m$^+$)	30	5.1	33.160	20.450	8.0	119.0	10.3	6.	0.13	0.88
8	1	6.1	33.404	20.900	8.1	120.0	10.2	2.	0.30	0.88
(1315,*	15	6.0	33.404	20.450	8.1	117.6	10.5	3.	0.62	0.88
40m$^+$)	30	6.0	33.426	20.750	8.0	117.6	10.3	3.	0.45	1.02

*Eastern Standard Time

$^+$Total Depth.

TABLE A-9
(continued)

DATA OF BACKGROUND STUDY
Cruise K-05-71, Mar. 10, 1971
Research Vessel KYMA

Station	Depth (meters)	Temp. (°C)	Salinity (0/00)	Chlorides (0/00)	pH	Alkalinity as $CaCO_3$ (mg/1)	D.O. (mg/1)	Total Iron (µg/1)	Total Phosphates (mg/1-PO_4)	Total Nitrogen (mg/1-N)
11 (0400*)	1	3.2		10.350	7.9	119.5	10.9	8.	0.12	1.00
13 (0240*)	1	2.8		15.750	7.9	98.0	11.1	10.	1.17	1.20

*Eastern Standard Time

TABLE A-10

SUBMARINE PHOTOMETER SUMMARY
OF
EXTINCTION COEFFICIENTS

Cruise K-05-71 March 10, 1971
Research Vessel KYMA

Station Number & Description	Extinction Coefficient $(ft)^{-1}$
Background	
#2 Depth = 130 ft.	0.085
#4 Depth = 130 ft.	0.077
#5 Depth = 135 ft.	0.079
#8 Depth = 130 ft.	0.058

at the 100-foot depth. Increased waste dilution was observed due, probably, to an increased mixing volume available in the absence of a thermocline. Settling of the waste to the bottom, if it occurs at all, will most likely occur under these conditions.

The background water column chemical data indicates no substantial change attributable to the disposal operations.

APPENDIX A-2

LABORATORY VERIFICATION OF THE SETTLING MODEL

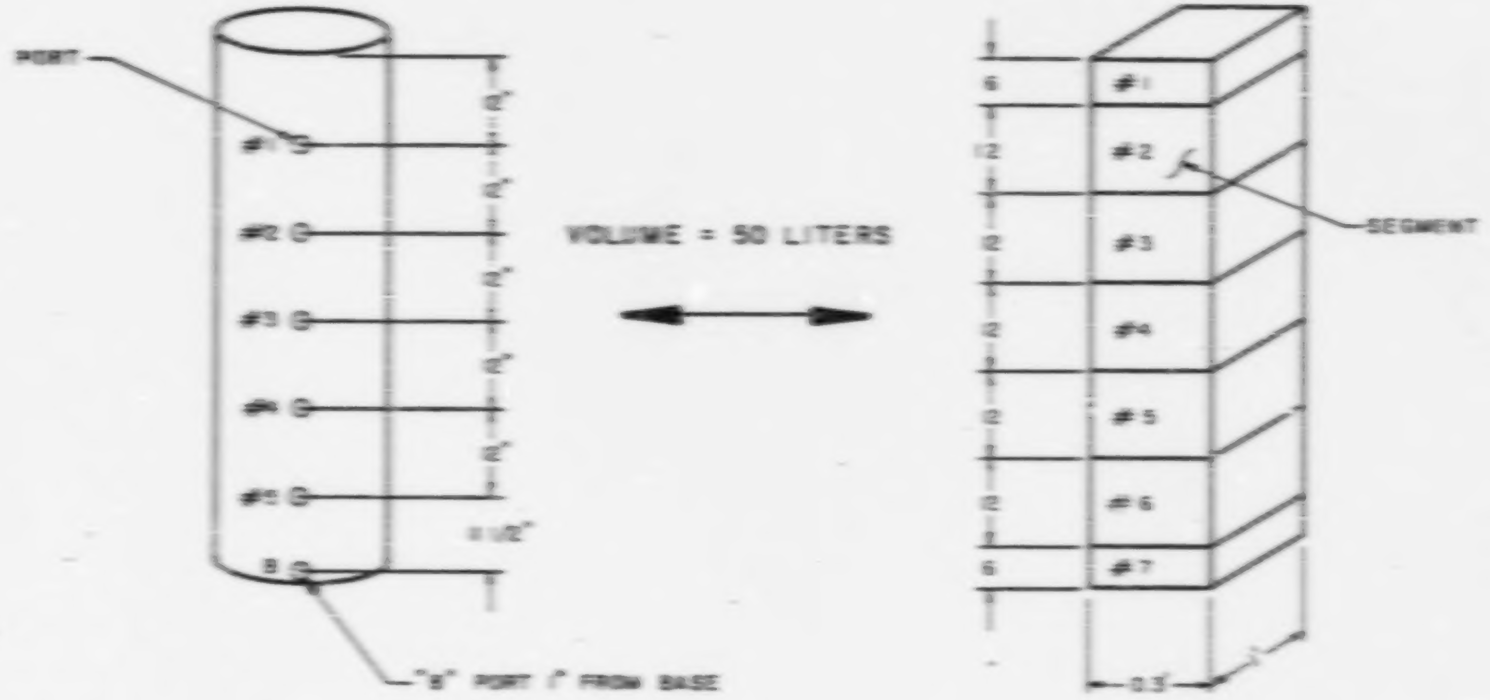
A settling column experiment was performed to measure the quiescient settling velocities of the waste in seawater, and to verify, under controlled conditions, the mathematical model based on the theory of discrete settling.

A six-foot column (Figure A-26) was filled with 50 liters of synthetic seawater containing:

Sodium Chloride (NaCl)	31 grams/liter
Magnesium Sulfate ($MgSO_4 \cdot 7H_2O$)	3 grams/liter
Sodium Bicarbonate ($NaHCO_3$)	0.3 grams/liter

Background iron concentration of the synthetic seawater was about 20 μg/l.

A waste sample was diluted to 100 mgFe/l and a volume (500 ml) taken which, if dispersed over the entire column volume, would yield a concentration of 1 mg/l. That volume was placed in a plastic bag over the column and then holes were punched in the bag simulating as well as possible dispersion in the field. Six sampling ports were indented about one inch into the column. A data summary is presented in Table A-11. Some interference during the latter stages (after two hours) of the experiment was noted, probably from laboratory thermal gradients in the water column. The data obtained after the first two hours has, therefore, been eliminated from the analysis. Data review also showed the concentration averaged over the six ports at any particular time was greater than 1 mgFe/l. Since the mathematical model conserves mass, the data was normalised (Table A-11) and are shown in Figure A-27.


PORT
#1
#2
#3
#4
#5
B
12"
12"
12"
12"
12"
1 1/2"
"B" PORT 1" FROM BASE
VOLUME = 50 LITERS
6
12
12
12
12
12
6
#1
#2
#3
#4
#5
#6
#7
SEGMENT
0.3'
1'

SETTLING COLUMN SET-UP

MATHEMATICAL MODEL SEGMENTATION

FIGURE A-26

SETTLING COLUMN EXPERIMENT

TABLE A-11

SETTLING COLUMN DATA

Iron Concentration (mg/l)
Time (minutes)

Location	Depth (ft.)	5	10	15	20	25	30	35	40	45	50	55	60	70	80	90	100	110	12
1	1	4.80	5.23	3.40	2.53	2.27	2.30	1.73	1.92	1.80	1.25	.930	.700	.700	.650	.520	.694	.640	.84
Normalized		4.06	3.06	2.27	1.74	1.58	1.36	.906	.882	.866	.765	.717	.582	.580	.580	.487	.600	.590	.74
2	2	2.20	4.90	4.75	4.00	3.13	3.00	3.93	3.07	2.40	1.65	1.30	1.15	1.07	.830	.680	.810	.670	.64
Normalized		1.86	2.87	3.17	2.76	2.18	1.77	2.06	1.41	1.16	1.01	1.00	.956	.837	.740	.637	.700	.617	.56
3	3	.022	.055	.665	2.05	2.87	3.93	3.93	4.75	3.63	2.75	1.90	1.90	1.53	1.30	.950	.852	.794	.79
Normalized		.019	.032	.444	1.41	2.00	2.32	2.06	2.18	1.75	1.68	1.47	1.58	1.27	1.16	.890	.735	.732	.70
4	4	.025	.025	.025	.077	.310	.875	1.80	3.13	3.65	3.27	2.70	2.20	2.30	1.75	1.55	1.30	1.03	1.0
Normalized		.021	.015	.017	.053	.216	.516	.942	1.44	1.75	2.00	2.08	1.83	1.91	1.56	1.45	1.12	.950	.91
5	5	.022	.018	.115	.023	.018	.037	.050	.180	.950	.830	.900	1.20	1.45	1.75	1.80	2.18	2.00	1.9
Normalized		.019	.011	.077	.016	.013	.022	.026	.083	.457	.507	.695	.997	1.20	1.56	1.69	1.89	1.84	1.6
3	6	.022	.023	.030	.025	.020	.015	.018	.020	.018	.050	.045	.063	.185	.440	.900	1.10	1.37	1.5
Normalized		.019	.013	.020	.017	.014	.011	.009	.009	.009	.031	.035	.052	.153	.392	.844	.953	1.26	1.3

Initial concentration = 100 mg/l - Total volume of waste is such that if dispersed over entire volume of the column, the resulting concentration would be 1.0 mg/l.

Initial Iron concentration in synthetic seawater = .020 mg/l.

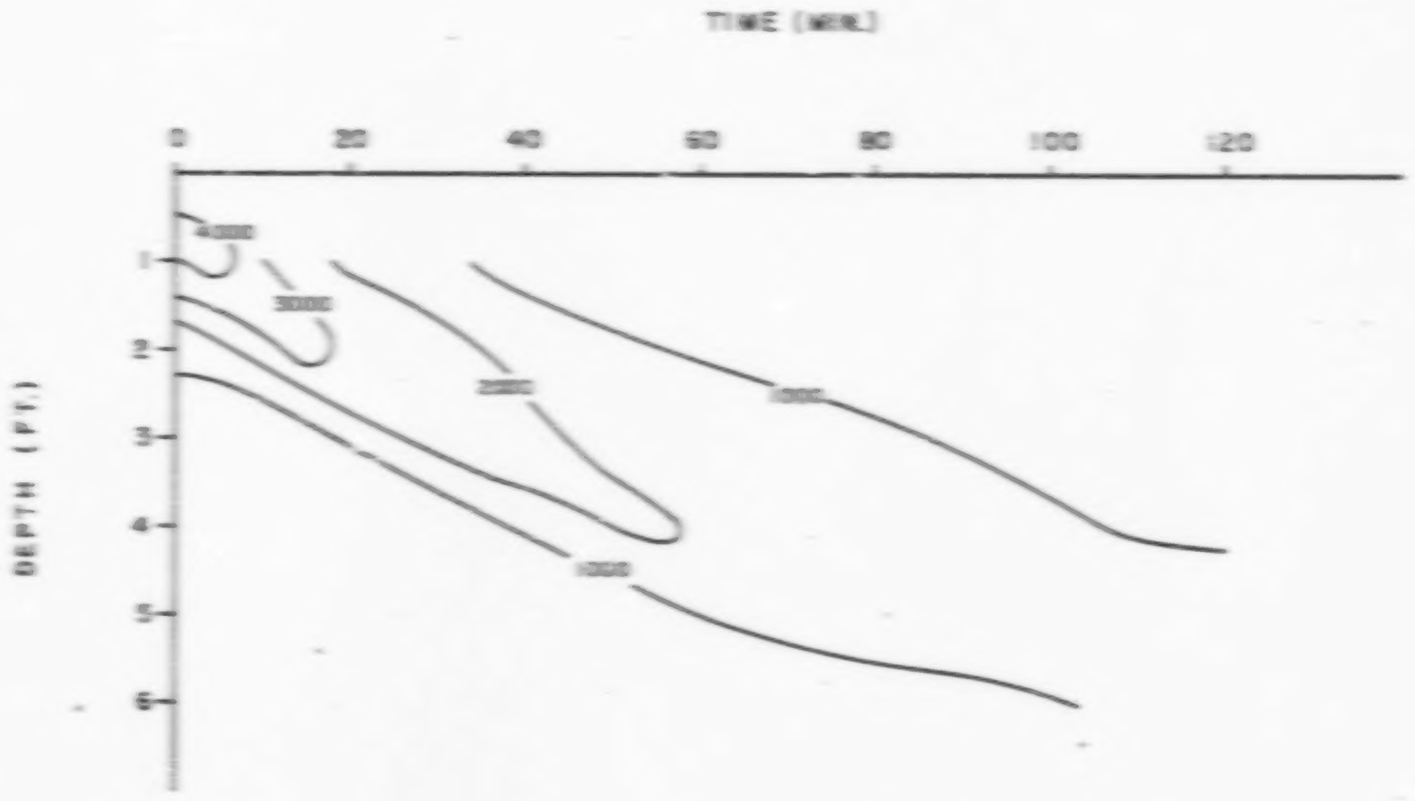


FIGURE B-27
NORMALIZED IRON DATA (μG/L)
OBTAINED IN LABORATORY

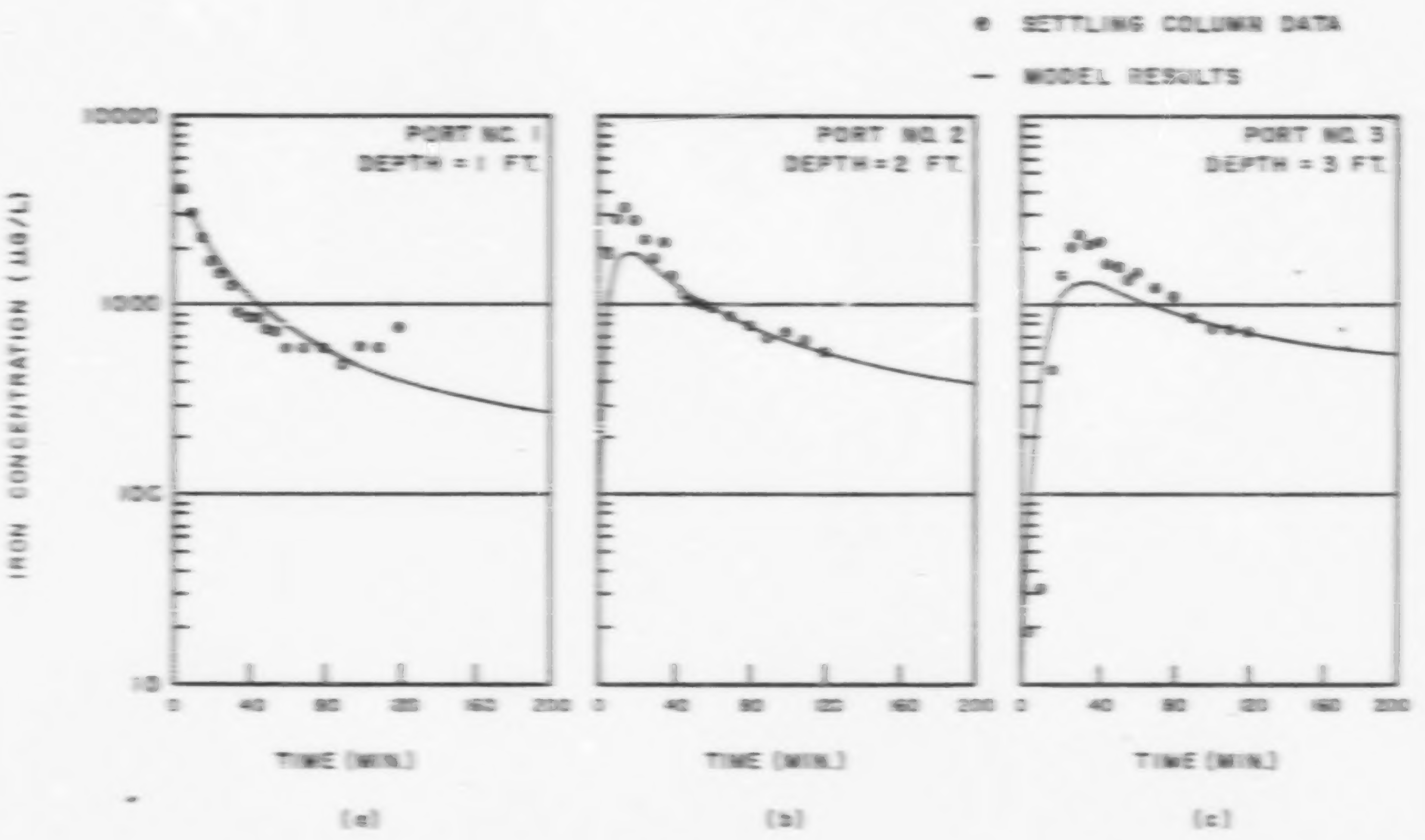


FIGURE 4-28 (a-c)
SETTLING COLUMN VERIFICATION

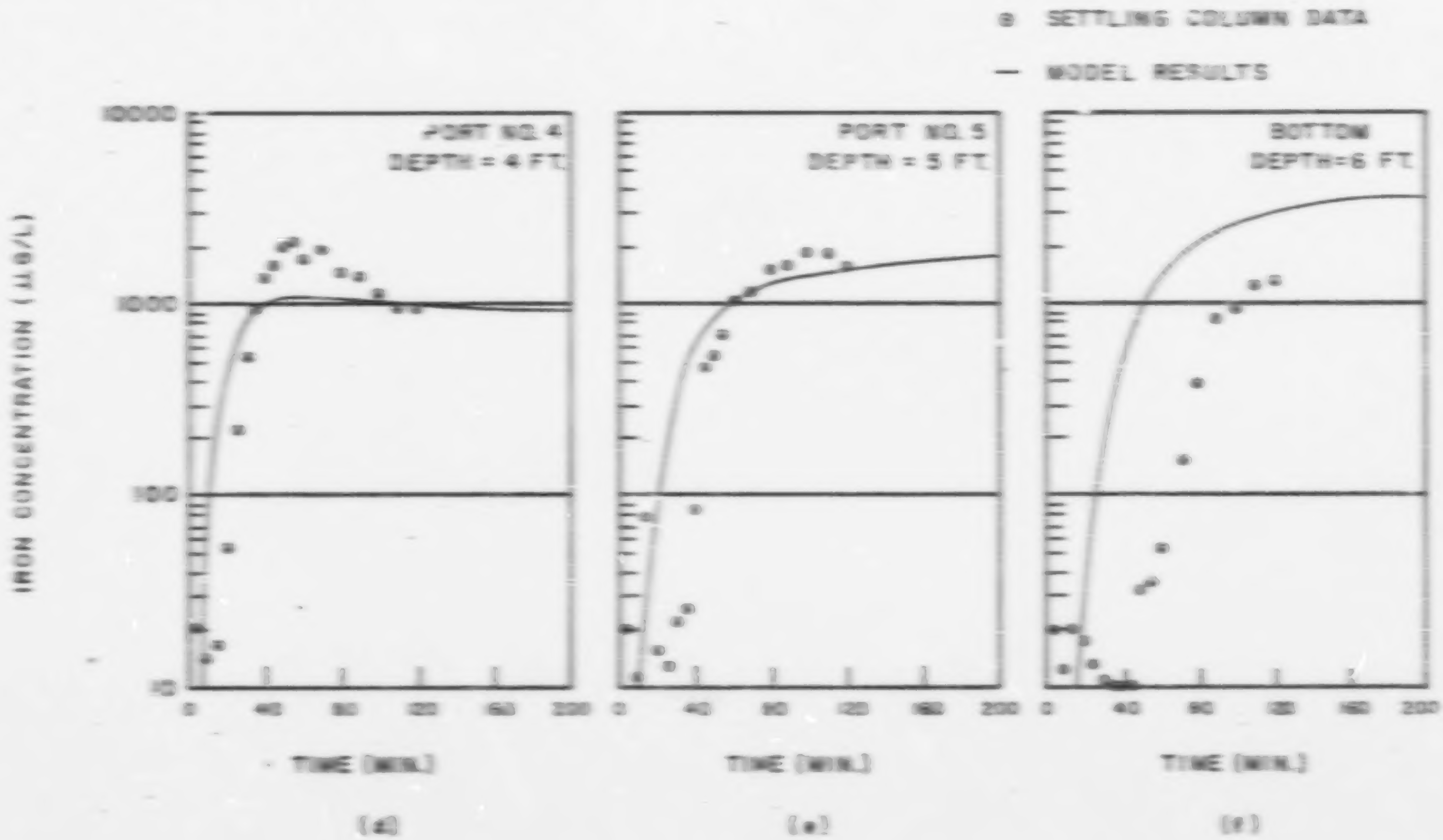


FIGURE A-26 (d-f)
SETTLING COLUMN VERIFICATION

Settling was simulated by seven model segments(Figure A-26). Instantaneously waste mixing in the first segment was assumed to give an initial input concentration of 12 mgFe/l. Each sampling port was generally located in the middle of each remaining six segments. The three parameters to be defined were the vertical dispersion coefficient (E_z) and the A and α constants associated with discrete settling (Appendix A-3). Figures A-28(a) through A-28(f) show the final verification run results. These figures compare normalized data with computed values for each port and segment as a function of time. The α term was calculated to be 6×10^{-6} gm/cm^3/(mg/l) for the waste sample used. The values of A and E_z used were 200 ft^2/min^2 and 0.5 cm^2/sec, respectively. Elimination of vertical dispersion for the last interface (between Segments 6 and 7) to simulate settling and accumulation of waste on the ocean bottom was not done because the vertical dispersion used in the laboratory verification represents diffusion on the molecular level. In the ocean, molecular diffusion is but a small fraction of the overall vertical dispersion phenomenon.

Laboratory verification was considered quite good. However, Figure A-28(f) shows some discrepancy at the last port. The presence of thermal gradients may explain this discrepancy. It was concluded, however, that the model did simulate the vertical diffusion and settling of the waste under controlled laboratory conditions and could, therefore, be applied with some degree of certainty to the oceanic model.

APPENDIX A-3

MATHEMATICAL MODEL DERIVATION

THEORY

The general mass balance equation describing the distribution of a conservative tracer material is:

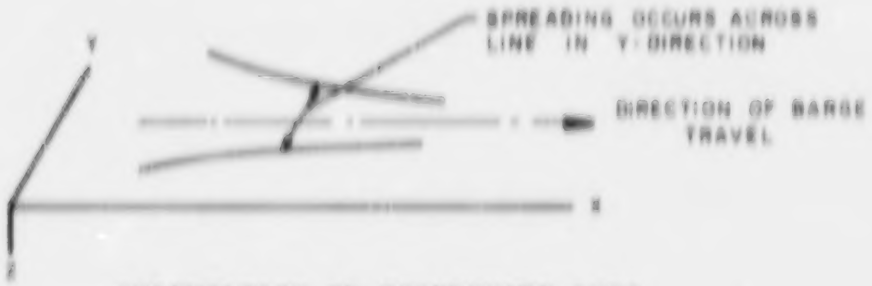
$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial x}\left(E_x \frac{\partial c}{\partial x}\right) + \frac{\partial}{\partial y}\left(E_y \frac{\partial c}{\partial y}\right) + \frac{\partial}{\partial z}\left(E_z \frac{\partial c}{\partial z}\right) - U\frac{\partial c}{\partial x} - V\frac{\partial c}{\partial y} - W\frac{\partial c}{\partial z} + S \quad \text{(A1)}$$

where:

c = concentration of tracer material (M/L^3)
x = distance in longitudinal direction (L)
y = distance in lateral direction (L)
z = distance in vertical direction (L)
t = time (T)
E = dispersion coefficient along indicated axis (L^2/T)
U = velocity in longitudinal direction (L/T)
V = velocity in lateral direction (L/T)
W = vertical settling velocity of the waste mass (L/T)
S = waste source (M/L^3T)
$\frac{\partial}{\partial x}\left(E_x \frac{\partial c}{\partial x}\right)$ = dispersion in longitudinal direction (M/L^3T)
$\frac{\partial}{\partial y}\left(E_y \frac{\partial c}{\partial y}\right)$ = dispersion in lateral direction (M/L^3T)
$\frac{\partial}{\partial z}\left(E_z \frac{\partial c}{\partial z}\right)$ = dispersion in vertical direction (M/L^3T)

and M, L, and T are the mass, length, and time units, respectively.

The coordinate axes are arranged as shown in Figure A-29:


SPREADING OCCURS ACROSS LINE IN Y-DIRECTION
Y
DIRECTION OF BARGE TRAVEL
X
Z

ORIENTATION OF COORDINATE AXES
FIGURE A-29

Assume:

1. A symmetrical dispersion pattern across the waste line;
2. Dispersion along the line of the waste plume can be neglected since longitudinal concentration gradients are considerably less than lateral and vertical gradients.

Further consideration of the waste field as to dispersing in some prevailing advective flow permits elimination of the longitudinal and lateral velocity terms, U and V, and use of a Lagrangian system of coordinates. A simplified equation then monitors the spreading waste, and the position of the entire field can be calculated from prevailing current velocities. With these assumptions, the temporal and spatial profiles are described by:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial y}\left(E_y \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(E_z \frac{\partial C}{\partial z}\right) - W\frac{\partial C}{\partial z} + S \qquad (A2)$$

The coordinates are now relative to the position of the centerline of the waste plume. Ketchum[37], in earlier work on waste disposal in the New York Bight, further simplified Equation (A2). Assume instantaneous mixing occurs both longitudinally and vertically, and the waste field is laid down instantaneously. Equation (A2) then simplifies to:

$$\frac{\partial c}{\partial t} = E_y \frac{\partial^2 c}{\partial y^2} + S \qquad (A3)$$

for constant lateral dispersion. For a column of water of 1 cm² cross section, the solution to equation (A2) is:

$$c = \frac{M'}{s\sqrt{2\pi}} \exp\left(-\frac{1}{2}(y/s)^2\right) \qquad (A4)$$

where:

$M' = \dfrac{\text{grams of waste discharged}}{\text{cm of barge travel in x direction}}$

$s = \sqrt{2E_y t}$

Equation (A4) has the form of a normal probability density function with y the random variable and s the standard deviation. At y = 0 (the centerline of spreading plume), the peak concentrations, Cp, are:

$$c_p = M'/s\sqrt{2\pi}$$

A very crude field estimate of the dispersion coefficient can be obtained by using the centerline concentration data to approximate the conditions which were assumed to arrive at Equation (A4). A plot of peak centerline concentrations (averaged over some depth) versus $1/\sqrt{t}$ should give a straight line, the slope of which is a measure of lateral dispersion. The major difficulty is the assumption of instantaneous vertical mixing. That assumption is inappropriate since one aspect of the problem is the degree to which waste interacts with the ocean bottom. Attempts to calculate lateral dispersion coefficients with Equation (A5) resulted in abnormally high lateral dispersion coefficients for the majority of the field studies. Apparently the need to assign a mixing depth, a priori, leads to significant errors. In addition, an average concentration must be estimated from a limited number of samples. The procedure was, therefore, not generally applied in this work.

Because of the settling characteristics of the waste, the vertical dimension was retained. This required further specification of waste settling in a variable density field. Use of a simple theoretical model for discrete particle settling approximated the vertical waste settling. The underlying equation is as follows[15]:

$$\frac{dW}{dt} = \frac{F}{\rho V} - g\left(\frac{\rho - \rho_o}{\rho}\right) - K\frac{\rho_o}{\rho}\frac{dW_\rho}{dt} + \frac{\rho_o}{\rho}\frac{dW_o}{dt} \qquad (A6)$$

where W is the instantaneous particle velocity with respect to ground, F is equal to the drag force, ρ equals particle density, ρ_o equals fluid density, V is the particle volume $(\pi d^3/6)$, $W^\rho = W - W_o$, where W_o is the vertical water velocity and K equals a constant. If one assumes $\frac{dW}{dt} = 0 = \frac{dW_o}{dt}$, and further lets:

$$F = A \, |W_\rho| \, W_\rho \qquad (A7)$$

where $A = f(C_d, d, \rho)$ with C_d the drag coefficient and d the particle diameter, an expression for the vertical velocity of the waste field in a quiescent medium is:

$$W = \left(A\left(\frac{\rho - \rho_o(z)}{\rho_o(z)}\right)\right)^{1/2} \qquad (A8)$$

where $\rho_o(z)$ is the density of the ocean as a function of depth. A simple assumption is made which relates the density of the dispersing waste field, ρ_t, to the waste concentration using surface seawater density. Thus:

$$\rho = \rho_o(0) + \alpha C \qquad (A9)$$

where α is a constant.

The vertical velocity is:

$$W = \left[A \left(\frac{\rho_o(0) + \alpha c - \rho_o(z)}{\rho_o(z)} \right) \right]^{1/2} \qquad (A10)$$

and the differential equation to be solved is:

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial y}\left(E_y \frac{\partial c}{\partial y}\right) + \frac{\partial}{\partial z}\left(E_z \frac{\partial c}{\partial z}\right) - \left(A \left(\frac{\rho_o(0) + \alpha c - \rho_o(z)}{\rho_o(z)} \right) \right)^{1/2} + S \qquad (A11)$$

The source term for Equation (A11) is given by the line source of tracer material laid down by the barge. Assume that the line is laid down instantaneously along the x-axis at time zero at position y = 0 and z = 0. Spreading therefore occurs laterally in the y direction (Figure A-29). The source term is written as:

$$S = M'\delta(y)\delta(z)\delta(t) \qquad (A12)$$

where:

$M' = \dfrac{\text{mass discharged}}{\text{length in x direction}}$

$\delta(y)$ = delta function in y-space

$\delta(z)$ = delta function in z-space

$\delta(t)$ = delta function in "time"

For a lower boundary condition, assume that any tracer material reaching the bottom (z = d) remains there.

Equation (A11) is a non-linear time-variable equation, and requires a finite difference scheme for computer solution.

NUMERICAL PROCEDURES

A finite difference approach[14] with a series of interconnected segments permits solving the non-linear differential equation proposed. It approximates the analytical solution in that the spatial domain is discretized into volume elements and spatial derivatives are replaced with difference expressions. For a single segment with volume V_k, the mass balance differential equation becomes:

$$\frac{dc_k}{dt} = \underbrace{\sum_{j \in n_k} \left(\frac{E'_{kj}}{V_k}(C_j - C_k)\right)}_{(1)} + \underbrace{\sum_{j \in n_k} \left(W(C_j, \rho_j, \rho_{oj}) C_j / L_j\right)}_{(2)} \underbrace{- W(C_k, \rho_k, \rho_{ok}) C_k / L_k}_{(3)} + \underbrace{S_k}_{(4)} \qquad \text{(A13)}$$

where:

C_k = concentration of tracer material in the segment $k(M/L^3)$

V_k = volume of segment $k(L^3)$

E'_{kj} = mixing rate of segment k from segment j (L^3/T) $E'_{kj} = E_{kj} A_{kj} / \bar{L}_{kj}$

E_{kj} = dispersion coefficient between segments k and j (L^2/T)

A_{kj} = cross-sectional area between segments k and j (L^2)

$\bar{L}_{kj}$ = average of characteristic lengths of segments k and j (L)

$W(c_k, \rho_k, \rho_{ok})$ = vertical settling velocity to segment j from segment k as determined from Equation (A10) (positive downward) (L/T)

L_k = vertical length of segment k (L)

S_k = source of variable c in segment k (M/L^3T)

$$S_k = \frac{M_k^{\phi}}{V_k}\,\delta(t)$$

M_k^{ϕ} = mass of tracer material in segment k

m_k = index set of segments adjacent to segment k

n_k = index set of segments above and below the segment k

and M, L, and T are the mass, length, and time units, respectively.

The first term on the righthand side of Equation (A13) represents both the lateral and vertical mixing effects. Constant dispersion coefficients are assumed. The second and third terms represent the vertical movement of the tracer material, a function of diluted waste concentration and density and seawater density. If the diluted waste density is less than the surrounding seawater density, a negative value is assigned the vertical velocity term obtained from Equation (A10) simulating an upward waste movement. The fourth term is the source term, treated as an initial condition in Segment 1 of the model at time zero. This initial condition is calculated from Equation (A5) from observed field parameters.

Equation (A12) is derived from Equation (A11) by use of central differences for the vertical dispersion term and backward differences for the vertical settling term. It is well known that the convective terms in equations similar to Equation (A13) are particularly troublesome in finite difference schemes. The use of backward differences (together with suitable time steps) generates positive stable solutions, but at the expense of introduction of numerical dispersion given by $W\Delta s/2$. For the problem at hand, it was felt that the amount of numerical dispersion so introduced was not a significant factor.

For a system of N segments, this structure results in a system of N simultaneous non-linear ordinary differential equations, which must be integrated. This is accomplished in the model by using a standard second-order Runge-Kutta numerical integration scheme. This involves a predictor-corrector method with half-step integration. For example, with c_0 the initial condition vector at time t_0, the predictor with a half-step integration is:

$$c^{*}_{\frac{1}{2}} = c_0 + \frac{h}{2} f(t_0, c_0) \qquad \text{(A14)}$$

where h equals the total time integration step (Δt). This value of c is used to estimate the slope of the midpoint of the interval, which is then used as the slope of the straight line approximation:

$$c_1 = c_0 + hf\left(t_0 + \frac{h}{2}, c^{*}_{\frac{1}{2}}\right) \qquad \text{(A15)}$$

This numerical method is accurate to terms of order Δt^2.

APPENDIX B-1

HYDROGRAPHIC DATA

Tables (B-1 to B-5)

Definition of Terms and Abbreviations:

$^o/_{oo}$ = parts/thousand

Sigma-t = sea water density at atmospheric pressure

$\text{Sigma-t} = (\rho_{s,t,o} - 1) \times 10^3$

O_2 Sat. = Dissolved oxygen saturation at indicated temperature and salinity

AOU = apparent oxygen utilization
= O_2 Sat. $- O_2$ of water sample

Conversion factor: Dissolved oxygen in mg/liter = 1.428 (concentration, ml/liter)

Table .-1

Cruise 5-06-70: 8 July 1970
Hydrographic Data

Station 2: 38°38.5'N, 74°20.0'W. 1903 hrs. EDST

Depth Meters	Temp. °C	Salinity o/oo	Sigma-t	pH	O_2 ml/l	O_2 Sat. ml/l	AOU ml/l
0	22.91	31.137	21.068	8.1	5.50	5.03	-0.47
10	22.06	31.294	21.417	8.1	5.61	5.10	-0.51
20	7.80	32.461	25.334	7.8	(6.20)	6.79	0.59
30	7.66	32.471	25.362	7.9	6.12	6.81	0.69
36	7.63	32.483	25.375	8.0	-	6.82	-

Station 5: 38°32.5'N, 74°20.0'W. 1539 hrs. EDST

Depth	Temp.	Salinity	Sigma-t	pH	O_2	O_2 Sat.	AOU
0	23.07	31.073	20.967	8.1	-	5.01	-
10	22.01	31.090	21.275	8.1	(5.59)	5.11	-0.48
25	10.28	32.248	24.782	8.0	7.37	6.43	-0.94
30	7.14	32.430	25.401	7.9	-	6.90	-
44	7.13	32.467	[illegible]	7.9	6.13	6.90	0.77

Station 8: 38°26.5'N, 74°20.0'W. 1046 hrs. EDST

Depth	Temp.	Salinity	Sigma-t	pH	O_2	O_2 Sat.	AOU
0	22.82	31.151	21.097	8.65	5.40	5.03	-0.37
10	21.66	31.295	21.458	8.15	5.75	5.15	-0.60
20	12.03	32.126	24.376	-	7.19	6.20	-0.99
30	6.88	32.385	25.400	8.0	6.60	6.95	0.35
38	6.86	32.397	25.412	8.0	-	6.96	-

Table B-2

Cruise S-09-70: 8 October 1970
Hydrographic Data

Station 2: 38°38.5'N, 74°20.0'W. 1949 hrs. EST

Depth Meters	Temp. °C	Salinity o/oo	Sigma-t	pH	O_2 ml/l	O_2 Sat. ml/l	AOU ml/l
1	22.09	31.581	21.624	7.55	5.32	5.09	-0.23
10	20.15	31.615	22.169	7.63	5.48	5.29	-0.19
20	20.09	31.664	22.212	7.63	5.23	5.29	0.06
25	13.60	31.782	23.807	7.32	5.37	6.02	0.65
30	9.44	31.871	24.625	7.30	(3.95)	6.60	(2.65)
37	9.13	31.887	24.687	7.32	4.06	6.63	2.57

Secchi disc = none, past sunset.

Station 5: 38°32.5'N, 74°20.0'W. 1517 hrs. EST

Depth	Temp.	Salinity	Sigma-t	pH	O_2	O_2 Sat.	AOU
1	20.51	31.625	22.076	7.74	5.38	5.25	-0.13
10	20.05	31.641	22.215	7.90	5.43	5.30	-0.13
20	14.48	31.729	23.586	7.66	(5.22)	5.91	0.69
25	8.86	31.906	24.744	7.51	—	6.66	—
30	8.23	31.932	24.857	7.62	4.23	6.75	2.52
42	7.78	31.941	24.960	7.52	—	6.82	—

Secchi disc = 15.5 meters at 1500 hrs.

Station 8: 38°26.5'N, 74°20.0'W. 1126 hrs. EST

Depth	Temp.	Salinity	Sigma-t	pH	O_2	O_2 Sat.	AOU
1	20.33	31.709	22.194	*8.13	—	5.23	—
15	20.03	31.706	22.270	8.06	5.62	5.29	-0.33
20	19.97	31.715	22.291	8.00	3.70	5.29	1.59
25	8.26	31.964	24.878	7.77	—	6.74	—
35	7.30	32.031	25.065	7.72	4.41	6.88	2.47
40	6.76	32.015	25.125	7.70	4.29	6.97	2.68

Secchi disc = 17.0 meters at 1107 hrs.

* pH readings not temperature corrected, this station only.

Table B-3

Cruise S-10-70: 17 November 1970
Hydrographic Data

Station 2: 38°38.5'N, 74°20.0'W. 1912 hrs. EST

Depth Meters	Temp. °C	Salinity o/oo	Sigma-t	pH	O_2 ml/l	O_2 Sat. ml/l	AOU ml/l
1	—	32.180	—	8.13	3.24	(6.00)	(2.76)
5	13.57	32.152	24.098	8.21	3.01	6.02	3.01
15	13.76	32.155	24.062	8.24	3.50	5.98	2.48
20	13.78	32.286	24.159	8.26	3.53	5.98	2.45
30	13.93	32.673	24.426	8.24	3.07	5.94	2.87
36	13.94	32.654	24.410	8.22	2.52	5.94	3.42

Station 5: 38°32.5'N, 74°20.0'W. 1420 hrs. EST

Depth	Temp.	Salinity	Sigma-t	pH	O_2	O_2 Sat.	AOU
1	13.82	32.385	24.224	8.15	3.76	5.95	2.19
10	13.84	32.393	24.230	8.20	4.05	5.95	1.90
20	13.86	32.477	24.290	8.21	3.36	5.96	2.60
25	14.15	32.782	24.465	8.20	2.78	5.92	3.14
30	14.11	32.813	24.496	8.20	2.87	5.91	3.04
47	14.05	32.898	24.574	8.22	2.90	5.91	3.01

Station 8: 38°26.5'N, 74°20.0'W. 1100 hrs. EST

Depth	Temp.	Salinity	Sigma-t	pH	O_2	O_2 Sat.	AOU
1	13.94	32.563	24.409	8.18	2.72	5.94	3.22
10	13.88	32.577	24.362	8.16	3.59	5.95	2.36
20	13.87	32.691	24.453	8.15	3.45	5.95	2.50
25	13.91	32.702	24.453	8.18	3.62	5.94	2.32
30	14.17	32.740	24.428	8.16	3.21	5.90	2.69
47	14.58	33.109	23.858	8.19	2.78	5.83	3.05

Table B-4

Cruise S-01-71: 29 January 1971
Hydrographic Data

Station 8: 38°26.5'N, 74°20.0'W. 1315 hrs. EST

Depth Meters	Temp. °C	Salinity o/oo	O_2 ml/l	O_2 Sat. ml/l	AOU ml/l
1	7.32	33.096	6.70	6.86	0.16
10	7.32	33.094	6.75	6.84	0.09
20	7.31	33.094	5.75	6.84	0.09
30	7.34	33.087	6.76	6.84	0.08
40	7.32	33.092	6.86	6.84	-0.02

Table B-5

Cruise 5-02-71: 27 May 1971
Hydrographic Data

Station 2: 38°38.5'N, 74°20.0'W. 1226 hrs. EDST

Depth Meters	Temp. °C	Salinity o/oo	Sigma-t	pH	O_2 ml/l	O_2 Sat. ml/l	AOU ml/l
0	13.72	31.692	23.712	8.12	6.42	5.99	-0.43
10	12.15	31.740	24.055	8.12	6.58	6.21	-0.37
15	11.34	31.883	24.312	8.15	7.43	6.30	-1.30
20	7.11	32.749	25.656	8.04	6.32	6.89	.57
30	7.11	32.754	25.656	8.03	6.28	6.89	.61
40	7.07	-	-	8.04	6.42	6.90	.48

Secchi disc = 11 meters at 1200 hrs.

Station 4: 38°32.5'N, 74°15.0'W. 1431 hrs. EDST

Depth	Temp.	Salinity	Sigma-t	pH	O_2	O_2 Sat.	AOU
0	15.23	31.662	23.374	8.20	6.32	5.82	-.50
10	13.09	-	-	8.17	6.53	6.08	-.45
17	12.47	-	-	8.17	6.62	6.18	-.44
22	7.25	32.670	25.574	8.09	6.60	6.89	.29
30	7.01	32.698	25.630	8.08	6.29	6.91	.62
40	7.01	32.691	25.606	8.08	6.26	6.91	.65

Secchi disc = none recorded.

Station 5: 38°32.5'N, 74°20.0'W. 1843 hrs. EDST

Depth	Temp.	Salinity	Sigma-t	pH	O_2	O_2 Sat.	AOU
0	[illegible]	-	-	8.20	6.25	5.83	-.42
10	[illegible]	31.276	23.552	8.20	6.39	6.13	-.26
15	12.35	31.517	23.849	8.20	6.38	6.17	-.21
20	7.77	32.638	25.477	8.17	6.97	6.78	-.19
30	7.18	32.622	25.555	8.13	6.18	6.91	.73
40	7.09	-	-	8.12	6.12	6.93	.81

Secchi disc = 9 meters at 1830 hrs.

Table B-5 (Continued)

Station 6: 38°32.5'N, 74°25.0'W. 2105 hrs. EDST

Depth	Temp.	Salinity	Sigma-t	pH	O_2	O_2 Sat.	AOU
0	14.92	31.200	23.088	8.21	6.32	5.83	-.49
10	12.86	31.572	23.790	8.20	6.45	6.11	-.34
15	12.03	-	-	8.21	6.46	6.21	-.25
20	8.12	-	-	8.22	6.92	6.72	-.20
30	7.17	32.745	25.648	8.13	6.40	6.88	.48
40	7.16	-	-	8.13	6.20	6.88	.68

Secchi disc = none, dark at secchi time of 2050

Station 8: 38°26.5'N, 74°20.0'W. 1635 hrs. EDST

Depth	Temp.	Salinity	Sigma-t	pH	O_2	O_2 Sat.	AOU
0	14.44	31.630	23.518	8.21	6.18	5.91	-.27
10	12.66	31.384	23.682	8.22	6.45	6.16	-.29
17	9.36	32.193	24.886	8.20	6.68	6.57	-.11
22	7.71	32.588	25.448	8.15	6.57	6.81	.24
30	7.13	32.724	25.630	8.13	6.16	6.86	.70
40	7.11	32.701	25.617	8.12	6.21	6.91	.70

Secchi disc = 9 meters at 1620 hrs.

APPENDIX B-2

BIOLOGICAL DATA

Phytoplankton (Tables B-6 to B-15)
Zooplankton (Tables B-16 to B-24)
Benthos and Fish (Tables B-25 to B-43)

Table B-6

CRUISE K-01-69 15 MAY 1969

Percent Composition by Species

SPECIES	STATIONS 2	4	5	6	8
Ceratium tripos	57	59	45	73	71
C. longipes	40	40	55	22	29
C. tripos f. lineatum	1	t	-	t	-
C. fusus	1	t	t	t	t
Peridinium sp.	1	t	t	5	t
Dinophysis sp.	t	1	t	t	t
C. macroceros	t	t	t	-	-
Foraminifera	-	t	-	-	-
Chaetoceros sp.	-	-	t	-	t

t = trace

- = not observed

Table B-7

CRUISE K-02-69 10 OCT. 1969

Percent Composition by Species

SPECIES	STATIONS		
	5	6	8
Nitzschia seriata	82	2	55
Thalassiosira sp.	2	67	30
Rhizosolenia alata	-	10	10
Rhizosolenia sp.	-	t	t
Chaetoceros sp.	t	-	t
Biddulphia sp.	5	21	t
Filamentous Blue Green	7	-	2
Coscinodiscus sp.	t	t	2
Ceratium tripos	t	-	t
C. tripos f. lineatum	-	-	t
C. fusus	t	t	t
C. macroceros	t	-	t
C. massiliense	-	-	t
Peridinium spp.	t	t	-
Unidentified pennate diatom	-	t	-
Ditylum brightwelli	-	t	-
UNIDENTIFIED CELL	4	-	-

t = trace

- = not observed

Table B-8

CRUISE 8-03-70 1 JUNE 1970

Percent Composition by Species

SPECIES	STATIONS 2	4	5	6	8
Ceratium tripos	80	90	91	95	82
C. fusus	16	4	4	3	t
C. longipes	3	6	4	1	17
Peridinium spp.	1	t	t	-	1
C. macroceros	t	t	1	t	-
Prorocentrum sp.	t	-	-	-	-

t = trace

- = not observed

Table B-9

CRUISE S-06-70 8 JULY 1970

Percent Composition by Species

SPECIES	STATIONS 2	 8	 5
Ceratium tripos	55	100	74
C. longipes	37	-	10
C. macroceros	t	t	t
Dinophysis sp.	-	-	9
Peridinium spp.	7	-	7
Unidentified concentric diatom	t	-	t
Unidentified pennate diatom	t	-	-
Foraminifera	-	-	t

t = trace

- = not observed

Table B-10

CRUISE K-04-70 5&6 Aug. 1970

Percent Composition by Species

SPECIES	STATIONS 2	4	5	6	8
Filamentous Blue Green	x	-	x	x	x
C. tripos	x	x	x	x	-
Peridinium sp. a	x	x	-		-
Prorocentrum	x	-	x	x	-
C. longipes	-	x	-	x	-
Dinophysis sp. a	-	-	x	-	-
C. fusus	-	-	-	x	-
C. macroceros	-	-	-	x	-
C. tripos f. lineatum	-	-	-	x	-
C. extensum	-	-	-	x	-
Peridinium sp. b	-	-	-	x	-
C. massiliense	-	-	-	x	-

x = present

- = not observed

Note: Percent composition not determined because of extremely low volume of phytoplankton.

Table B-11

CRUISE 8-09-70 8 Oct. 1970

Percent Composition by Species

SPECIES	STATIONS 2	5	8
Ceratium tripos	2	1	3
C. fusus	t	1	1
C. macroceros	2	10	2
C. massiliense	t	7	t
Peridinium sp.	3	6	1
Filamentous Blue Green	93	75	91
C. extensum	t	t	-
C. carriense	-	t	-
Foraminifera	-	t	-
Radiolarian	-	-	t
Chaetoceros sp.	-	-	1

t = trace

- = not observed

Table B-12

CRUISE B-10-70 17 NOV. 1970

Percent Composition by Species

SPECIES	STATIONS 2	 5	 8
Stephanopyxis turris	57	68	76
Stephanopyxis palmeriana	–	–	t
Rhizosolenia alata	36	26	9
Rhizosolenia sp.	t	t	t
Nitzschia seriata	–	4	9
Coscinodiscus spp.	1	t	t
Ceratium tripos	1	1	1
C. tripos f. lineatum	t	t	t
C. macroceros	1	t	t
C. fusus	1	t	t
Pennate diatom (*Pleurosigma*?)	t	1	t
Thalassiosira sp.	t	t	2
Thalassionema nitzschiodes	1	t	2
Guinardia flaccida	2	t	t
Lithodesmium undulatum	–	t	t
Radiolarian	t	t	t
Chaetoceros sp.	1	t	2
Ditylum brightwellii	–	t	t

Table B-12 (concluded)

SPECIES	STATIONS		
	7	5	8
Peridinium sp.	t	t	-
Nitzschia sp.	-	t	-
Filamentous Blue Green	-	-	t
unidentified chain form	t	-	-

t = trace

- = not observed

Table B-13

CRUISE S-01-71 19 JANUARY 1971

Percent Composition by Species

SPECIES	STATION 8
Ceratium tripos	74
C. macroceros	2
C. fusus	t
C. longipes	t
Guinardia flaccida	7
Chaetoceros sp.	7
Coscinodiscus sp.	2
Rhizosolenia sp.	1
Thalassionema nitzschiodes	t
Foraminifera	t
Peridinium	t
Biddulphia sinensis	7
Unidentified sp.	t

t = trace

- = not observed

Table B-14

CRUISE K-03-71 10 MARCH 1971

Percent Composition by Species

SPECIES	STATIONS				
	2	4	5	6	8
Guinardia flaccida	92	19	70	64.9	56
Ceratium tripos	2	64	18	27.5	34
C. macroceros	t	4	1	t	2
C. longipes	1	-	1	t	t
C. fusus	t	1	t	.4	1
Coscinodiscus spp.	t	-	t	-	t
Rhizosolenia spp.	t	1	1	.6	1
Rhizosolenia alata	1	2	2	.8	2
Chaetoceros sp.	2	7	7	5	2
Thalassionema nitzschiodes	t	1	1	t	-
Unidentified arced chain	3	t	t	-	1
Unidentified filament	1	-	-	-	-
Unidentified chain form	t	-	t	-	t
Pennate diatom	t	-	-	-	-
Biddulphia sinensis	-	t	t	.4	t
Foraminifera	-	-	t	-	t
Ceratium tripos f. lineatum	-	-	t	t	1

t = trace

- = not observed

Table B-15

CRUISE S-02-71 27 May 1971

Percent Composition by Species

SPECIES	STATIONS 2	4	5	6	8
Ceratium tripos	79	70	85.3	70.8	79.3
C. tripos f. lineatum	4.3	2.9	t	.8	t
C. longipes	15.5	19.2	7.3	12.3	12.6
Dinophysis spp (1&2)	t	1.5	t	1	2.7
Protoceratium	3.3	5	2.0	3.3	1.8
Guinardia flaccida	t	-	2.3	6.4	-
C. macroceros	t	1.3	t	t	.5
Peridinium sp. d	t	t	t	1.7	.5
Rhizosolenia sp.	t	-	-	-	t
C. fusus	t	t	3.0	3.6	2.3
aberrant form of *Ceratium*	-	-	-	8	-
Peridinium sp.	-	-	-	-	t

t = trace

- = not observed

Table B-26- Presence of zooplankton. X = present, Number = #/sample (no flow meter on this cruise).

B-01-69 (15 May 1969)

SPECIES	Station 2		Station 4		Station 5		Station 6		Station 8	
	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep
Copepoda										
Centropages typicus	x	–	x	–	x	–	x	–	x	–
Calanus finmarchicus	x	x	–	x	x	x	x	x	–	x
Pseudocalanus minutus	x	x	–	x	x	x	x	x	x	x
Paracalanus parvus	–	x	–	–	–	x	x	–	–	x
Temora longicornis	–	x	–	x	–	x	–	x	–	x
Tortanus discaudatus	–	–	–	–	x	–	x	x	–	–
Metridia lucens	–	–	–	x	–	x	x	x	–	–
Oithona similis	x	x	x	x	x	x	x	x	x	–
Oithona sp.	–	x	–	x	–	x	–	x	x	x
Acartia longiremis	x	x	–	–	–	–	–	–	–	x
Acartia sp.	–	–	–	x	–	–	–	–	–	–
Copepodites	x	x	x	x	–	–	x	x	–	–
Cladocera										
Evadne nordmanni & (*Podon leuckarti*)	18,375	16,000	11,875	31,750	187,500	11,250	335,360	23,750	18,750	9,375
Other forms										
Sagitta sp.	x	763	x	2,375	–	1,237	–	7,600	1,513	725
Limacina retroversa	–	1,075	–	x	–	x	25,400	x	–	1,213
Leptomedusae	–	463	13	387	100,000	1,375	55,200	887	775	413
unidentified eggs	x	–	1,813	487	–	–	–	x	2,813	x
fish eggs	2,963	63	1,750	125	6,200	13	6,600	100	3,087	–
fish larvae	–	113	–	213	–	137	–	38	–	50
Oikopleura sp.	–	x	x	x	–	578	–	x	–	–

Table B-16, cont'd

SPECIES	Station 2 Surface	Station 2 Deep	Station 4 Surface	Station 4 Deep	Station 5 Surface	Station 5 Deep	Station 6 Surface	Station 6 Deep	Station 8 Surface	Station 8 Deep
mysid shrimp	–	37	–	–	–	13	–	–	–	–
unidentified coelenterate	–	–	–	100	–	–	–	x	–	x
polyps	–	–		–	–	–	–	–	–	113
Larval forms										
crab zoea	–	100	–	125	–	–	3,800	–	–	13
shrimp zoea	–	–	–	37	–	–	600	–	–	–
polychaete larvae	–	x	–	x	–	x	–	–	–	x
pluteus larvae	x	–	–	x	–	x	–	–	–	x
anthozoan larvae	–	x	–	x	–	x	–	x	–	x
bipinnaria larvae	–	x	–	x	–	–	–	–	–	x

Table 3-27. Abundance of zooplankton. #/100 m^3.

K-02-69 (11 October 1969)

SPECIES	Station 5		Station 6		Station 8	
	Surface	Deep	Surface	Deep	Surface	Deep
Copepoda						
Centropages typicus	6045	*(53)	298	281	*(447)	*(372)
Oncaea venusta	2364	(19)	1261	2459	(421)	(237)
Corycaeus spp.	1976	(12)	806	707	(461)	(150)
Temora turbinata	2975	(18)	667	545	(279)	(146)
T. stylifera	317	(6)	32	112	(38)	(8)
Candacia armata	188	(8)	473	67	(94)	(94)
Copilia mirabilis	-	-	-	22	(1)	(1)
Sapphirina nigromaculata	23	-	-	79	(6)	(3)
Labidocera aestiva	12	-	-	-	-	-
harpacticoid	22	-	-	-	(2)	-
copepodites	-	-	65	460	-	-
Cladocera						
Evadne nordmanni	7456	(25)	11	34	(260)	(136)
Podon sp.	212	(1)	75	79	(8)	(7)
Other forms						
Sagitta sp.	23	(17)	75	56	(7)	(17)
Doliolum sp.	253	(1)	2645	4233	(1)	(4)
Oikopleura sp.	2552	(16)	1580	1224	(136)	(68)
polychaete	12	-	11	11	(9)	-
ctenophore	-	-	-	12	-	(1)
hyperiid amphipod	129	(9)	11	56	(21)	(32)
benthic amphipod	-	-	-	-	(1)	(1)
Limacina retroversa	-	-	11	-	(1)	-
Creseis sp.	-	(5)	-	34	(4)	(5)
Cavolina sp.	-	-	-	-	-	(3)

Broken Flow Meter. ( ) = #/sample.

Table B-17 (concluded)

SPECIES	Station 5		Station 6		Station 8	
	Surface	Deep	Surface	Deep	Surface	Deep
heteropod	23	–	–	–	(8)	(1)
salps	–	–	–	–	–	(4)
mysid shrimp	–	–	–	–	(56)	–
hydromedusae	–	–				
fish eggs	153	(1)	32	–	(14)	(8)
fish larvae	106	–	97	45	(9)	–
Anthomedusae	82	–	118	236	(1)	(8)
Leptomedusae	–	–	65	11	(2)	–
Siphonophores	247	(38)	226	247	(7)	(38)
Isopods					(122)	(4)
Larval forms						
crab zoea	12	(2)	–	303	(3)	(8)
megalopa	–	–	11	–	–	(1)
pluteus larvae	–	(2)	86	34	–	–
Thalassinidae larvae	–	–	32	11	(1)	–
veligers	–	–	22	–	–	–

Table B-19. Abundance of zooplankton per 100m^3

S-03-70 (1 June 1970)

SPECIES	Station 2		Station 4		Station 5		Station 6		Station 8	
	Surface	Deep*	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep
Centropages typicus	3250	(254)	417	178	3069	31	674	96	–	675
C. hamatus	–	–	–	–	–	–	–	–	5	–
Calanus finmarchicus	300	(496)	250	535	256	46	–	770	8	1125
Pseudocalanus minutus	545794	(17952)	9583	4812	1509	95	72	2021	72	2250
Paracalanus parvus	113	(6336)	–	5881	4266	95	357	3850	44	4050
Temora longicornis	–	(1272)	367	535	52	26	–	–	8	–
Acartia longiremis	–	(64)	83	–	52	–	–	–	7	113
Oithona similis	225	(496)	256	713	–	–	176	674	105	563
Oithona sp.	–	–	–	–	208	–	–	289	–	–
Metridia lucens	–	(8)	–	178	–	–	–	193	–	–
Oncaea spp.	–	–	–	–	–	–	–	–	5	–
Copepodites	225	(1152)	417	1426	5098	36	3250	866	225	450
Cladocera										
Evadne nordmanni	9	–	386	24	60	–	254	–	468	99
Podon leuckarti	5	–	3	86	–	–	–	50	–	67
Other forms										
Sagitta sp.	409	(72)	47	157	21	–	1	215	4	171
Limacina retroversa	401	–	538	5322	4	5610	10	3323	4	–
Leptomedusae	77	(24)	8500	121	1073	14	–	19	–	133
Oikopleura sp.	–	(232)	–	321	–	61	–	54	–	185
Paguridae	77	(40)	–	7	–	–	1	17	–	120
fish eggs	5	–	13	7	21	–	138	–	27	–

*Broken flowmeter.
( ) = Total #/sample.

Table B-18 (concluded)

SPECIES	Station 2		Station 4		Station 5		Station 6		Station 8	
	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep
fish larvae	189	(88)	3	28	-	-	-	7	-	27
Larval forms										
crab zoea	1031	(24)	-	-	-	-	-	12	-	-
shrimp zoea	-	-	-	-	-	-	-	28	-	5
pluteus larvae	-	-	-	-	-	-	-	-	1	-
polychaete larvae	-	(8)	-	-	-	7	-	4	-	13
Anthozoan larvae	-	-	-	7	-	-	-	-	-	9
veligers	5	(26)	-	63	-	-	-	-	-	54

Table 3-23. Abundance of zooplankton per 100m.^{3}

S-06-70 (8 July 1970)

SPECIES	Station 2		Station 5		Station 8	
	Surface	Deep	Surface	Deep	Surface	Deep
Copepoda						
Centropages typicus	21323	— Not Analyzed. —	213	708	226	3880
Calanus finmarchicus	-		-	325	36	363
Pseudocalanus minutus	3215		-	1214	-	960
Paracalanus parvus	10246		107	1567	180	2296
Temora longicornis	-		29	354	-	-
Acartia longiremis	831		29	50	-	180
Oithona similis	4154		70	2073	-	3480
Copepodites	8585		1367	1770	7056	7340
Cladocera						
Evadne nordmanni	22		-	-	251	26
Penilia avirostris	-		-	-	-	13
Other forms						
Sagitta sp.	11		3	1025	6	26
pagurids	11		-	79	-	-
Oikopleura sp.	2957		1131	262	245	1144
Limacina retroversa	-		-	838	10	39
Amphipods	-		-	2	-	26
Ostracod	-		-	-	-	26
medusae	-		-	-	-	13
fish eggs	226		97	2	36	116
fish larvae	22		-	-	-	26
Larval forms						
crab zoea	11		-	-	1	76
megalopa	-		-	4	-	-
straight hinged veliger	-		-	-	-	13
gastropod veliger	-		-	-	-	13

Table 3-20. Abundance of zooplankton per 100m.^{3}

K-04-70 (5 August 1970)

SPECIES	Station 2		Station 4		Station 5		Station 6		Station 8	
	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep
Copepoda										
Centropages typicus	639	(22)	210	72	(68)	(24)	— Not Analyzed —	(8)	–	–
C. hamatus	–	–	–	–	–	–		–	–	(8)
C. bradyi	–	–	–	–	–	–		–	–	(8)
Calanus finmarchicus	–	–	5	–	–	–		(8)	(4)	(56)
Pseudocalanus minutus	–	(18)	107	9	–	(2)		(8)	–	(120)
Paracalanus parvus	359	(6)	64	90	(48)	(38)		(60)	(82)	(1376)
Eucalanus sp.	24	–	–	–	–	–		–	(2)	–
Calocalanus pavo	–	(8)	–	–	–	–		–	–	–
Oithona similis	18	(144)	24	117	(8)	(226)		(216)	(6)	(1480)
Oithona sp.	6	(16)	–	–	–	–		(12)	–	–
Oncaea venusta	–	–	5	45	(73)	–		(4)	–	(16)
Oncaea sp.	282	–	–	–	–	–		–	(12)	–
Corycaeus spp.	559	(42)	70	63	(10)	(52)		(40)	(48)	(224)
Copilia mirabilis	36	–	–	9	–	–		–	–	(26)
Temora stylifera	6	–	–	–	(2)	–		–	(4)	–
T. longicornis	–	–	24	–	–	–		–	(2)	(80)
T. turbinata	–	–	–	–	–	(4)		–	–	–
Euchaeta marina	–	–	–	–	–	(2)		–	–	–
Euterpina acutifrons	24	–	–	18	(2)	–		(4)	–	–
Copepodites	18	(148)	9	9	(4)	(50)		(104)	(12)	(544)
Cladocera										
Evadne nordmanni	1891	(52)	1309	153	(178)	(218)		(900)	(392)	(512)
E. spinifera	2909	(8)	325	153	(258)	(200)		(32)	(150)	(96)

( ) - #/sample

Table B-27 (concluded)

SPECIES	Station 2 Surface	Station 2 Deep	Station 4 Surface	Station 4 Deep	Station 5 Surface	Station 5 Deep	Station 6 Surface	Station 6 Deep	Station 8 Surface	Station 8 Deep
Penilia avirostris	1605	(98)	–	621	(20)	(438)	— Not Analysed —	(224)	(32)	(72)
Podon leuckarti	–	–	–	–	–	(2)		(28)	–	(16)
Other forms										
Sagitta sp.	–	–	–	–	–	(4)		(8)	(2)	(8)
Limacina retroversa	–	(102)	18	–	(4)	(2)		(92)	–	(16)
Doliolum nationalis	1421		706	617	(138)			(36)	(58)	(3136)
Thalia democratica	109	(2)	145	126	(2)	(38)		(4)	(26)	(88)
ctenophora	–	–	24	–	–	–		–	–	–
Anthomedusae	6	–	5		(2)	–		(4)	(2)	(8)
unidentified coelenterate	–	(10)	–	–	–	–		–	–	(8)
siphonophora	–	–	5	–	–	–		(12)	(2)	(56)
Ostracod	6	–	–	–	–	–		–	–	–
Oikopleura sp.	423	(98)	547	99	(88)	(48)		(64)	(264)	(40)
fish eggs	6	–	–	–	(6)	–		–	(18)	–
fish larvae	24	–	5	–	(2)	–		(4)	–	–
Larval forms										
crab zoea	12	–	75	–	(6)	–		–	(6)	(24)
shrimp zoea	–	–	–	–	–	–		–	–	(16)
pluteus larvae	55	–	–	18	(2)	(126)		(36)	–	(408)
Anthozoan larvae	–	–	–	–	–	(2)		–	–	(16)
unidentified larval form	–	–	–	18	–	–		–	–	–

Table B-21. Abundance of zooplankton per 100m.^{3}

S-09-70 (8 October 1970)

SPECIES	Station 7		Station 5		Station 8	
	Surface	Deep	Surface	Deep	Surface	Deep
Copepoda						
Centropages typicus	2686	769	6124	3873	5365	216
C. furcatus	–	256	–	–	–	–
Calanus finmarchicus	298	–	978	739	1904	108
Pseudocalanus minutus	4476	4100	1712	2029	6317	649
Paracalanus parvus	23276	3075	–	–	–	–
Temora stylifera	–	256	–	185	–	–
T. longicornis	298	–	–	–	–	–
Oncaea venusta	3282	2819	1467	185	260	108
Corycaeus spp.	3879	256	–	738	2259	216
Acartia danae	–	256	–	–	–	–
Tortanus discaudatus	–	256	–	–	–	–
Euchaeta marina	–	256	–	–	–	–
Undinula vulgaris	298	–	–	–	–	–
Copepodites	3879	1025	3690	738	3289	108
nauplii	–	–	–	185	865	–
Cladocera						
Evadne nordmanni	–	–	–	185	528	378
E. spinifera	–	–	244	–	–	–
Podon sp.	–	–	–	–	–	541
Penilia avirostris	–	–	–	369	1385	108
unidentified sp.	–	–	978	–	–	–
Other forms						
Sagitta sp.	298	–	244	185	86	324
Creseis virgula conica	298	–	–	–	–	–
Creseis sp.	–	–	244	185	86	–
unidentified pteropod	–	–	244	–	–	–

Table B-21 (concluded)

SPECIES	Station 7		Station 5		Station 8	
	Surface	Deep	Surface	Deep	Surface	Deep
Oikopleura sp.	2984	74	4647	2504	3894	–
Doliolum sp.	2984	–	–	–	4413	324
salps	–	–	–	–	–	108
Lucifer faxoni	298	–	–	–	–	–
juvenile cumacean	298	–	–	–	–	–
hyperiid amphipod	–	16	244	185	5	–
benthic amphipod	–	16	–	–	–	–
polychaete	–	57	–	–	3	–
siphonophore	895				86	
radiolarian	–	–	244	–	173	–
unidentified eggs	597	–	–	–	–	–
Scyphozoa	4					
Larval forms						
crab zoea	–	8	–	–	–	–
gastropod veliger	–	–	–	185	–	324
bivalve veliger	–	–	–	–	–	541

Table 3-22. Abundance of zooplankton per 100M^3 X = present in trace quantities.

S-10-70 (17 November 1970)

SPECIES	Station 2 Surface	Station 2 Deep	Station 5 Surface	Station 5 Deep	Station 8 Surface	Station 8 Deep
Copepoda						
Centropages typica	5737	688	6250	357	921	Not Properly Preserved
C. bradyi	–	–	x	–	–	
Calanus finmarchicus	3866	207	x	x	–	
Nannocalanus minor	374	x	–	89	–	
Calocalanus pavo	x	–	–	89	–	
Pseudocalanus minutus	42907	895	18125	2411	658	
Eucalanus sp.	x	–	–	–	–	
Oncaea venusta	16339	551	2625	179	3158	
Corycaeus spp.	1372	207	500	89	131	
Temora turbinata	–	–	–	179	–	
T. stylifera	125	–	x	x	–	
Candacia armata	x	69	–	–	–	
C. pachydactyla	–	–	x	–	–	
Acartia spp.	–	620	x	–	–	
Oithona sp.	748	–	4625	446	4211	
Rhincalanus cornutus	–	–	–	x	–	
Euchaeta marina	x	–	–	x	–	
Scolecithrix danae	x	–	–	x	–	
Undinula vulgaris	x	–	–	–	–	
Sapphirina nigromaculata	x	–	–	–	–	
Macrosetella gracilis	–	–	–	–	x	
unidentified harpacticoids	873	–	x	85	–	
copepodites	11724	1859	30300	2549	10921	
Cladocera						
Evadne nordmanni	125	–	–	–	131	
Podon leuckarti	–	–	–	x	–	
Penilia avirostris	–	–	–	–	131	

Table B-22 (concluded)

SPECIES	Station 2		Station 5		Station 8	
	Surface	Deep	Surface	Deep	Surface	Deep
Other forms						
Limacina retroversa	1247	895	625	893	1857	
Creseis sp.	248	–	–	179	394	
heteropod	–	69	4	–	–	
Sagitta sp.	371	31	212	81	14079	
Oikopleura sp.	249	–	250	175	526	
Doliolids	249	–	125	–	–	
salps	–	2	–	–	–	Not Properly Preserved
polychaete	125	8	8	26	–	
mysid shrimp	12	5	–	6	–	
hyperiid amphipod	28	3	4	4	131	
phronimid amphipod	8	–	–	–	–	
benthic amphipod	–	1	–	–	–	
hydromedusae	–	2	–	–	131	
siphonophore	–	–	4	–	–	
Ostracod	–	–	–	7	1	
unidentified coelenterate	–	–	250	268	–	
radiolarian	–	–	–	89	–	
foraminifera	–	–	–	–	526	
fish larvae	12	5	–	–	–	
fish eggs	8	–	8	–	263	
Larval forms						
crab zoea	–	–	–	3	–	
megalops	–	–	4	–	–	
bivalve veligers	3617	2892	2750	3214	2500	
gastropod veligers	–	69	–	–	–	
cyphonaute larvae	–	–	–	–	131	
pluteus larvae	248	–	1000	268	921	
Ephyra larvae	125	–	–	–	–	

Table 9-25. Abundance of zooplankton per 100m.^{3} X = present in trace quantity.

(S-02-71 (29 January 1971)

SPECIES	Station 8 Surface
Copepoda	
Centropages typicus	6923
C. bradyi	X
Pseudocalanus minutus	33750
Paracalanus parvus	X
Eucalanus sp.	X
Oithona sp.	865
Corycaeus sp.	X
Oncaea sp.	X
Scolecithrix danae	X
Nannocalanus minor	X
Copepodites	17307
Cladocera	
Podon intermedius	865
Other forms	
Limacina retroversa	47596
Immature *Creseis* sp.	1731
Larval form	
bivalve veliger	1731

Table B-24. Abundance of zooplankton per 100m.³ I - Present in trace quantity.

S-02-71 (27 May 1971

SPECIES	Station 2 Surface	Station 2 Deep	Station 4 Surface	Station 4 Deep	Station 5 Surface	Station 5 Deep	Station 6 Surface	Station 6 Deep	Station 3 Surface	Station 3 Deep
Copepoda										
Centropages typicus	–	–	871	195	1812	–	–	243	813	–
C. hamatus	44	–	–	–	–	–	–	–	–	–
Calanus finmarchicus	44	154	I	2754	–	2407	374	974	203	
Pseudocalanus minutus	–	154	1163	1953	279	3502	374	5234	1118	3792
Paracalanus parvus	–	I	–	3125	418	7879	498	7305	102	–
Oithona similis	221	6618	4215	4102	557	1751	1744	1461	6911	505
Acartia longiremis	–	308		–	139	–	623	1218	–	–
Oithona sp.	–	I	–	I	–	438	–	–	–	–
Temora turbinata	–	–	–	–	–	–	–	736	–	–
Tortanus discaudatus	–	I	I	–	I	–	I	–	–	–
Copepodites	310	–	3634	195	1115	3721	1619	2678	8333	–
Cladocera										
Evadne nordmanni	–	–	–	6	–	–	–	4	5	–
Other forms										
Sagitta sp.	–	1386	42	2734	837	2407	872	3166	35	505
Limacina retroversa	–	960	–	–	279	657	1744	203	26	32
ctenophore	–	–	5	–	–	–	–	–	–	–
medusae	–	154	–	–	–	–	–	–	–	253
mysid shrimp	–	–	–	586	–	219	249	16	3	–
fish larvae	–	63	7	63	17	179	374	85	3	28
fish eggs	44	5	2	–	–	–	–	4	3	–
unidentified egg	–	154	–	–	–	–	–	–	–	–

Table B-24 (concluded)

SPECIES	Station 2		Station 4		Station 5		Station 6		Station 8	
	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep
Larval form										
crab zoea	–	4081	60	63	6413	111	872	63	11	8
shrimp zoea	–	148	–	–	–	–	227	4	–	–
gastropod veliger	89	308	–	29299	5	2723	1121	40909	1321	3792
bivalve veliger	–	–	–	195	–	219	–	243	–	8
anthozoan larvae	–	–	–	143	–	657	–	78	3	24

Table B-25

Small Biological Trawl Cruise List

Cruise	Date	Stations
K-01-69	15 May 1969	2, 4, 5, 6, 8
K-02-69	11 Oct 1969	5, 6, 8
B-02-70	25 May 1970	2, 4, 5, 6
B-03-70	1 June 1970	6, 8
B-06-70	8 July 1970	2, 5 8
B-07-70	5 Aug 1970	2, 4, 5, 6, 8
B-09-70	8 Oct 1970	2, 5, 8
B-10-70	17 Nov 1970	2, 5, 8
B-01-71	19 Jan 1971	8
K-01-71	10 Mar 1971	2, 4, 5, 6, 8
B-03-71	1 June 1971	5, 8

Table B-26

Otter Trawls
Cruise List

Cruise	Date	Station
F-01-69	28 May 1969	2, 4, 5, 8
S-02-70	25 May 1970	2, 4, 5, 6, 8
S-03-70	1 June 1970	8
S-06-70	8 July 1970	2, 5, 8
S-07-70	5 Aug 1970	2, 4, 5, 6, 8
S-09-70	8 Oct	2, 5, 8
S-10-70	17 Nov 1970	2, 5, 8
S-03-71	1 June	2, 5, 6, 8

Table B-27

Small Biological Trawl
Species List
Station 2

CRUISE	B-01-69	S-02-70	S-06-70	S-07-70	S-09-70	S-10-70	B-01-71
FORAMINIFERA							
Astrorhiza limnicola or *hancocki*	1			762	many		x
PORIFERA	x						
yellow sponge		x					x
unidentified #1						1	x
unidentified #1					1		
ECTOPROCTS							
Eucratia lorica							x
HYDROIDS							
Obelia					1		
ASCIDIAN							
Bostrichobranchus pilularis				94			x
ECHINODERMS							
small urchin							x
Asterias sp.		x					
Asterias forbesi				36			4
Asterias vulgaris							2
Echinarachnius parma	x	x		763	89		516
Echinarachnius parma (dead)				2	10		
BIVALVES							
Anadara transversa							
Arctica islandica		x					18
Astarte sp.					1		
Astarte castanea	2						
Cardita borealis				1			5
Placopectin magellanicus						1	1
GASTROPODS							
Crius stimpsoni				1	1		
Crucibulum striatum					2		
Elysia sp.				18	4		
Lunatia (*Polinices*) *heros*							1
Nassarius trivittatus	2			6	4		10
Solariella obscura				1			15

Table B-27 (continued)

CRUISE	E-01-69	S-02-70	S-06-70	S-07-70	S-09-70	S-10-70	E-01-71
AMPHIPODS							
unidentified	47						
Aeginina longicornis	1			16			
Ampelisca acherisicum							1
Corophium macrocephala							1
Lysianopsis alba							1
Paraphoxus spinosus					2		
Unciola irrorata							6
ISOPODS							
Aveinnus depressus							2
Edotea montosa				2			
CUMACEANS							
Diastylis quadrispinosa				1			
unidentified	17						
DECAPODS							
Cancer irroratus - adult	2				29		
Cancer irroratus - juvenile				851	224		1
Hippolyte sp.		x		34	63		4
Pagurus annulipes				19	4		23
Crangon septemspinosum				418	76		195
POLYCHAETES							
Arabella irrocolor							2
unidentified	1						
Syllid							x
WORMS - not polychaetes	10						
FISH							
Citharichthys arctifrons				1			4
Flounder juvenile				17	1		
skate egg cases							x
unidentified	1						
SHELL							
Arctica		x		11-1 clap			18

Table 8-27 (concluded)

	CRUISE	K-01-69	S-02-70	S-06-70	S-07-70	S-09-70	S-10-70	K-07-71
Crassostrea virginica					3			
Ensis directus					3			
Placopectin magellanicus			x					1
Spisula					38-1 clap			4
unknown		3						
Data from sorted sample		x			x	x	x	x
Data from station log sheet			x					

Table B-28

Small Biological Trawl
Species List
Station 4

	CRUISE	K-01-69	S-02-70	S-07-70	K-01-71
FORAMINIFERA					
Astrorhiza limnicola or *hancocki*					x
Haplofragmoides (?)		x			
ASCIDIANS					
Bostrichobranchus pilularis				524	x
ECHINODERMS					
Asterias forbesi		x		2	1
Echinarachnius parma				352	28
Echinarachnius parma (dead)				27	10
BIVALVES					
Arctica islandica					1 juv.
Astarte castanea					3
Cardita borealis					1
Ensis directus					3
Anadara		x			
GASTROPODS					
Elysia sp.				21	
Lunatia (Polinices) heros					3 juv.
Solariella obscura					5
unidentified		23			
CEPHALAPODS					
Loligo pealei					1
AMPHIPODS					
Aeginina longicornis					1
Leptocheirus pinguis					1
Paraphoxus spinosus					3
Phoxocephalus holbolli					2
Unciola irrorata					7
unidentified		11			
ISOPODS					
Cirolana concharum					1
Edotea montosa				1	6
unidentified		5			

Table B-28 (concluded)

	CRUISE	8-01-69	5-02-70	5-07-70	8-01-71
CUMACEANS					
unidentified		13			
DECAPODS					
Cancer irroratus		x		505	1 juv.
Hippolyte sp.				21	
Pagurus annulipes				9	3
Crangon septemspinosum				193	13
unidentified crab		1			
unidentified shr'mp		1			
HYDROIDS					
Obelia longissima					x
Other					x
SIPUNCULOIDEA					
Phasc[illegible]on strombi					1
POLYCHAETES					
Clymenella		2			
Lumbrineris acuta					1
Syllis					1
unidentified		4			
FISH					
flounder - juvenile				4	
SHELL					
Arctica islandica				2 clap	
Crassostrea virginica				3	
Ensis directus				1	
Placopectin magellanicus				1	
Spisula				1	
UNKNOWN		4			
STATION LOG: Small orange worms in net mesh			x		
Data from sorted sample		x		x	x
Data from station log sheet			x		

Table B-29

Small Biological Trawl
Species List
Station 5

CRUISE	E-01-69	E-02-69	S-02-70	S-06-70	S-07-70	S-09-70	S-10-70	E-01-71	S-03-71
FORAMINIFERA									
Astrorhiza limnicola or *hancocki*	x				790	many		many	many
PORIFERA									
yellow sponge				x				x	
unidentified #1					2			peice	
ASCIDIANS									
Bostrichobranchus pilularis					308			x	x
ECHINODERMS									
Asterias sp.	x		x						
Asterias forbesi				16	25	17		2	2
Asterias vulgaris						2		5	1
Henricia sanguinolenta				3					
Echinarachnius parma			x		466	282	60	412	572
Echinarachnius parma (dead)					74	55		23	4
BIVALVES									
Pelecypods - unidentified	11								
Arctica islandica	x		x	81	2		x	15	
Astarte castanea									5
Cardita borealis						6		64	21
Crassostrea virginica				3					
Ensis directus								10	5
Lyonsia hyalina					5			14	
Mercenaria mercenaria				x					
Placopecten magellanicus				x		1			
Spisula solidissima			x	1			1		
GASTROPODS									
unidentified	8								
Elysia sp.						4			
Lunatia (Polinices) heros								16	5
Polinices egg collar						1			
Solariella obscura					4				5
Nassarius trivittatus								16	

Table B-29 (continued)

CRUISE	E-[illegible]-69	E-[illegible]-69	S-[illegible]-70	S-[illegible]-70	S-[illegible]-70	S-[illegible]-70	S-[illegible]-70	E-[illegible]-71	S-[illegible]-71
CEPHALAPODS									
Loligo pealei						1			
AMPHIPODS									
unidentified	15				1				
Aeginina longicornis					3	1			
Ampelesia compressa								6	11
Ampelesia abdita								1	
Corophium acherusicum								30	
Elasmopus pocillimanus									2
Listriella clymenella									3
Lysianopsis alba								6	5
Paraphoxus spinosus								227	18
Unciola irrotata					9			200	107
ISOPODS									
Ancinus depressus									1
Cirolana concharum								3	
Edotea montosa					3	1		3	16
unidentified	2								
CUMACEANS									
Diastylis sculpta					1			129	10
unidentified	3								
Cyclaspis varians								50	
Eudorellopsis deformis								9	
Eudorella truncatula								19	
Petalosarsia declivis								11	
DECAPODS									
Cancer sp.			5					8	
Cancer irroratus - adult				2	412		1		
Cancer irroratus - juvenile						319	13	2	1
Hippolyte sp.					8	65		3	45
Libinia dubia									1
Pagurus annulipes					9		4	6	1
Crangon septemspinosum					377	126		985	327
unidentified crab	1								
unidentified shrimp	1								

Table B-29 (concluded)

CRUISE	K-01-69	K-02-69	S-02-70	S-06-70	S-07-70	S-09-70	S-10-70	K-01-71	S-13-71
POLYCHAETES									
Clymenella	2								
Glycera americana									2
Nephthys coeca									1
Polynoidae (Harmanthas extenuata)						1			
Syllid									1
worm tubes	x								
FISH									
Anguilla					1				
Citharichthys arctifrons					1				
Lephophidium cervinum					1				
Urophycis sp.						8		1	
Urophycis regius				1					1
flounder - juvenile						9			35
fish eggs	x								
fish larvae						1		15	1
Prionotu - juvenile								1	
Arctica islandica				15 clap	17	1 clap	3 clap		1
Aquipecten irradians						1			
Cardita borealis						13			
Crassostrea virginica					3				
Placopecten magellanicus						13			4
Solariella obscura						1			
Spisula solidissima					10	4			
fossil oyster								x	
UNKNOWN	3								
Data from sorted sample	x				x	x	x	x	x
Data from station log sheet		x	x				x		

Table B-30

Small Biological Trawl
Species List
Station 6

CRUISE	K-01-69	K-02-69	S-02-70	S-03-70	S-07-70	K-01-71	S-03-71
FORAMINIFERA							
Astrorhiza limnicola or *hancocki*		x			441	many	many
Haplofragmoides (?)	TMTC	x					
ASCIDIANS							
Rostrichobranchus pilularis					140	x	x
ENCHINODERMS							
Asterias sp.	x	25					
Asterias forbesi	3				28	11	
Asterias vulgaris						3	
Echinarachnius parma		39			86	136	232
Echinarachnius parma (dead)					3	126	
Ophiuroidea		1					
PORIFERA		x				x	
BIVALVES							
Arctica islandica						28	
Pelecypoda (unidentified)	28	43					
Anadera transvusa	1						
Astarte castanea	10					1	
Cardita borealis					1	16	2
Ensis directus					1		2
Lyonsia hyalina	39						2
Placopecten magellanicus					2		
Pandora gouldiana						1	
GASTROPODS							
Elysia sp.					20		
Solariella obscura					2		1
unidentified	16	22					
Lunatia heros						1	
Nassarius trivittatus						1	
AMPHIPODS							
Ampelisca compressa							3
Corophium acherusicum							13
Lysianopsis alba							3
Paraphoxus spinosus						3	26
Phoxocephalus holbolli							8

Table B-30 (continued)

	CRUISE [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Stenthoe gallensis	23						
Unciola irrorata					6		26
unidentified	TMTC	63					
Hippomedon serratus						1	
ISOPODS							
Edotea montosa	TMTC				3		1
Ptilanthura tricarina	30						
unidentified		49					
Cirolana concharum						5	
BRYOZOAN							
unidentified					2		
CUMACEAN							
unidentified	TMTC	7					
Diastylis sculpta					2		6
Leptocuma minor							3
DECAPODS							
Cancer irroratus		10			574	1	
Hippolyte sp.	7				29	5	
Pagurus annulipes					13	6	
Crangon septemspinosum	7	46			370	7	49
unidentified	x	84					
POLYCHAETES							
Aphrodita hastata	18	2					
Clymenella	160	9					
unidentified	11	25					
worm tubes	x						
FISH							
flounder - juvenile					14		49
unidentified	5					2	
Urophycis juvenile						1	
SHELL							
Arctica islandica					37 1 clap	1 clap	

Table B-30 (concluded)

CRUISE	8-02-69	8-02-69	5-02-70	5-03-70	5-07-70	8-01-71	5-03-71
Placopecten magellanicus					2		
Spisula					1		
UNKNOWN	8						
Data from sorted sample	x	x			x	x	x
Data from station log sheet							

Table B-31

Small Biological Trawl
Species List
Station 8

CRUISE	8-01-69	8-02-69	5-03-70	5-06-70	5-07-70	5-09-70	5-10-70	5-01-71	8-01-71	5-03-71
FORAMINIFERA										
Astrorhiza limnicola or *hancocki*	x		x		184	many				x
PORIFERA										
unidentified #1					1				x	
unidentified #3						x				
HYDROIDS										
Obelia						few				
ASCIDIANS										
Bostrichobranchus pilularis					329					x
ECHINODERMS										
Asterias sp.	x		10							
Asterias forbesi					14	23				1
Asterias vulgaris					1	897				
Echinarachnius parma	x		300		697	324	65		71	175
Echinarachnius parma - dead					5	9			10	
BIVALVES										
Pelecypods - unidentified	9									
Arctica islandica			x	44		1	22			2 juv.
Astarte castanea										11
Cardita borealis					3	1				5
Ensis directus				3					3	10
Lyonsia hyalina										11
Periploma leanum				2	2	3				
Placopectin magellanicus				9	3	1				
Spisula solidissima				30			28	3	1	1 juv.
Pandora gouldiana								2		
GASTROPODS										
unidentified	4									
Elysia sp.					6	3				2
Littorina obtusa						?				
Lunatia (Polinices) heros					1				6	1
Lunatia triseriatta										1
Nassarius trivittatus										1
Solariella obscura					3	9			5	4

Table B-31 (continued)

	[illegible] 8-07-69	8-02-69	5-03-70	5-06-70	5-07-70	5-09-70	5-10-70	5-01-71	8-01-71	5-03-71
SQUID										
Loligo pealei									1	
AMPHIPODS										
unidentified	25									
Aeginina longicornis					15	2				
Ampelesca acherisicum										1
Ampelesca compressa										1
Byblis serrata					1					
Corophium macrocephala										1
Corophium sp.									2	
Lysianopsis alba										1
Paraphoxus spinosus					6				1	7
Unciola irrorata					12	1				15
unknown (Pleustidae)					1					
ISOPODS										
Aveinnus depressus										2
Chiridotea coeca										1
Chiridotea tuftsi					7					
Edotea montosa					24				2	18
Idotea phosphorea					38	1				
unidentified	34				1					
CUMACEANS										
Diastylis sculpta					9					1
unidentified	4									
DECAPODS										
Cancer sp.			2							
Cancer irroratus - adult						1				
Cancer irroratus - juv.					613	450				1
Hippolyte sp.					3	15			3	26
Pagurus annulipes					4	6			3	
Pagurus longicarpus					1					
Crangon septemspinosum	4				83	40			50	111
unidentified shrimp	1									
POLYCHAETES										
Glycera americana										2
Lumbrinaris fragilis										1

Table B-31 (concluded)

	CRUISE 8-02-69	8-02-69	5-03-70	5-06-70	5-07-70	5-08-70	5-10-70	5-02-71	8-03-71	5-03-71
Nepthys bucera										1
Nereis diversicolor										1
unidentified	5									
worm tubes	x									
Maldanid fragment									1	
FISH										
Anguilla rostrata										2
Urophycis sp.				1						
flounder - juvenile					4	2				7
fish larvae									2	1
unidentified						2				
Prionotus juvenile									1	
SHELL										
Arctica				30 clap				4 + 2 clap		
Ensis directus				1/2 clap						
cockle				2						
fossil oyster				45						
Placopecten								1		
Spisula								7		
UNKNOWN	6			1						
Data from sorted sample	x				x	x			x	x
Data from station log			x	x			x	x		

Table B-12

Small Biological Trawl
(SBT) Species Summary

SPECIES	STATIONS 2 A	B	4 A	B	5 A	B	6 A	B	8 A	B
FORAMINIFERA										
Astrorhiza limicola or hancocki	4/5	80	1/3	33	4/4	100	3/4	75	4/4	100
Haplofragmoides	-	-	1/3	33	-	-	2/4	50	-	-
PORIFERA	1/6	16	-	-	-	-	1/4	25	-	-
yellow sponge	2/6	33	-	-	2/8	25	-	-	-	-
unidentified #1	2/6	33	-	-	1/4	25	-	-	1/4	25
unidentified #3	1/6	16	-	-	-	-	-	-	1/4	25
ECTOPROCTS										
Eucratia lorica	1/5	20	-	-	-	-	-	-	-	-
HYDROIDS										
Obelia	1/5	20	-	-	-	-	-	-	1/4	25
Obelia longissima	-	-	1/3	33	-	-	-	-	-	-
Other	-	-	1/3	33	-	-	-	-	-	-
ASCIDIANS										
Bostrichobranchus pilularis	2/5	40	2/3	66	2/4	50	2/4	50	2/4	50
ECHINODERMS										
Asterias sp.	1/5	20	-	-	2/8	25	2/5	40	2/8	25
Asterias forbesi	2/5	40	3/3	100	4/8	50	2/5	40	3/8	37
Asterias vulgaris	1/5	20	-	-	2/8	25	-	-	2/8	25
Henricia sanguinolenta	-	-	-	-	1/4	25	-	-	-	-
Ophiopholis aculeata	-	-	-	-	-	-	-	-	-	-
Echinarachnius parma	5/6	83	2/3	66	5/8	62	3/5	60	6/8	75
Ophiurodea	-	-	-	-	-	-	1/5	20	-	-
small urchin	1/5	20	-	-	-	-	-	-	-	-
BIVALVES										
Pelecypods (unidentified)	-	-	-	-	1/4	25	2/4	50	1/4	25
Anadara transversa	-	-	1/3	33	-	-	1/4	25	-	-
Arctica islandica	2/5	40	1/3	33	5/8	62	1/4	25	5/8	62
Astarte sp.	1/5	20	-	-	-	-	-	-	-	-
Astarte castanea	1/5	20	1/3	33	1/4	25	1/4	25	1/4	25
Cardita borealis	2/5	40	1/3	33	2/4	50	2/4	50	3/4	75
Crassostrea virginica	-	-	-	-	1/8	12	-	-	-	-

Column A = # of times species occurs at station/# cruises data available for that station.

Column B = column A expressed as percent.

Table B-12 (continued)

SPECIES	STATIONS 2		4		5		6		8	
	A	B	A	B	A	B	A	B	A	B
Ensis directus	-	-	1/3	33	1/4	25	2/4	50	2/4	50
Lyonsia hyalina	-	-	-	-	1/4	25	2/4	50	1/4	25
Mercenaria	-	-	-	-	1/8	12	-	-	-	-
Periploma leanum	-	-	-	-	-	-	-	-	3/4	75
Placopecten magellanicus	2/5	40	-	-	2/8	25	1/4	25	3/8	37
Spisula solidissima	-	-	-	-	3/8	37	-	-	4/8	50
GASTROPODS										
unidentified	-	-	1/3	33	1/4	25	2/4	50	1/4	25
Colus stimpsoni	2/5	40	-	-	-	-	-	-	-	-
Crucibulum striatum	1/5	20	-	-	-	-	-	-	-	-
Elysia sp.	2/5	40	1/3	33	1/4	25	1/4	25	3/4	75
Littorina obtusa	-	-	-	-	-	-	-	-	1/4	25
Lunatia (Polinices) heros	1/5	20	1/3	33	1/4	25	-	-	2/4	50
Lunatia triseriata	-	-	-	-	-	-	-	-	1/4	25
Nassarius trivittatus	4/5	80	-	-	-	-	-	-	1/4	25
Polinices egg collar	-	-	-	-	1/4	25	-	-	-	-
Solariella obscura	2/5	40	1/3	33	2/4	50	2/4	50	3/4	75
CEPHALAPODS										
Loligo pealei	-	-	1/3	33	1/4	25	-	-	-	-
AMPHIPODS										
unidentified	1/5	20	1/3	33	2/4	50	2/4	50	1/4	25
Aeginina longicornis	2/5	40	1/3	33	2/4	50	-	-	2/4	50
Ampelisca acherissecum	1/5	20	-	-	-	-	-	-	1/4	25
Ampelisca compressa	-	-	-	-	1/4	25	1/4	25	1/4	25
Byblis serrata	-	-	-	-	-	-	-	-	1/4	25
Corophium acherusicum	-	-	-	-	-	-	1/4	25	-	-
Corophium macrocephala	1/5	20	-	-	-	-	-	-	1/4	25
Elasmopus pocillimanus	-	-	-	-	1/4	25	-	-	-	-
Leptochirus pinguis	-	-	1/3	33	-	-	-	-	-	-
Listriella clymenella	-	-	-	-	1/4	25	-	-	-	-
Lysianopsis alba	1/5	20	-	-	1/4	25	1/4	25	1/4	25
Paraphoxus spinosus	1/5	20	1/3	33	1/4	25	1/4	25	2/4	50
Phoxocephalus holbolli	-	-	1/3	33	-	-	1/4	25	-	-
Stenothoi gallensis	-	-	-	-	-	-	1/4	25	-	-
Unciola irrorata	1/5	20	1/3	33	2/4	50	2/4	50	3/4	75
unknown (Pleustidae)	-	-	-	-	-	-	-	-	1/4	25
ISOPODS										
Ancinus depressus	-	-	-	-	1/4	25	-	-	1/4	25
Aveinnus depressus	1/4	25	-	-	-	-	-	-	-	-

Table B-32 (continued)

SPECIES	STATIONS									
	2		4		5		6		8	
	A	B	A	B	A	B	A	B	A	B
Cirolana concharum	-	-	1/3	33	-	-	-	-	-	-
Chiridotea caeca	-	-	-	-	-	-	-	-	1/4	25
Chiridotea tuftsi	-	-	-	-	-	-	-	-	1/4	25
Edotea montosa	1/5	20	2/3	66	3/4	75	3/4	75	2/4	50
Idotea phosphorea	-	-	-	-	-	-	-	-	2/4	50
Ptilanthura tricarina	-	-	-	-	-	-	1/4	25	-	-
unidentified	-	-	1/3	33	1/4	25	1/4	25	2/4	50
BRYOZOAN - unidentified	-	-	-	-	-	-	1/4	25	-	-
CUMACEANS										
Leptocuma minor	-	-	-	-	-	-	1/4	25	-	-
Diastylis quadrispinosa	1/5	20	-	-	-	-	-	-	-	-
Diastylis sculpta	-	-	-	-	2/4	50	2/4	50	2/4	50
unidentified	1/5	20	1/3	33	1/4	25	2/4	50	1/4	25
DECAPODS										
Cancer sp.	-	-	-	-	2/8	25	-	-	1/8	12
Cancer irroratus	4/5	80	3/3	100	4/4	100	2/5	40	3/8	37
Hippolyte sp.	4/5	80	1/3	33	3/4	75	2/4	50	3/4	75
Librinia dubia	-	-	-	-	1/4	25	-	-	-	-
Pagurus annulipes	3/5	60	2/3	66	3/4	75	1/4	25	2/4	50
Pagurus longicarpus	-	-	-	-	-	-	-	-	1/4	25
Crangon septemspinosum	3/5	60	2/3	66	3/4	75	4/4	100	4/4	100
unidentified crab	-	-	1/3	33	1/4	25	2/4	50	-	-
unidentified shrimp	-	-	1/3	33	1/4	25	2/4	50	1/4	25
SIPUNCULOIDEA										
Phascolion strombi	-	-	1/3	33	-	-	-	-	-	-
POLYCHAETES										
Arabella irracolor	1/5	20	-	-	-	-	-	-	-	-
Aphrodita hastata	-	-	-	-	-	-	2/4	50	-	-
Clymenella	-	-	1/3	33	1/4	25	2/4	50	-	-
Glycera americana	-	-	-	-	1/4	25	-	-	1/4	25
Lumbrinaris fragilis	-	-	-	-	-	-	-	-	1/4	25
Lumbrineris acuta	-	-	1/3	33	-	-	-	-	-	-
Nephthys caeca	-	-	-	-	1/4	25	-	-	-	-
Nephthys bucera	-	-	-	-	-	-	-	-	1/4	25
Neries diversicolor	-	-	-	-	-	-	-	-	1/4	25
Polynoidae (prob: *Harmothoe extenuata*)	-	-	-	-	1/4	25	-	-	-	-
Syllid	1/5	20	1/3	33	1/4	25	-	-	-	-

Table B-32 (concluded)

SPECIES	STATIONS 2		4		5		6		8	
	A	B	A	B	A	B	A	B	A	B
unidentified	1/5	20	1/3	33	-	-	2/4	50	1/4	25
worm tubes	-	-	-	-	1/4	25	1/4	25	1/4	25
WORMS - not polychaetes	1/5	20	-	-	-	-	-	-	-	-
FISH										
Anguilla rostrata	-	-	-	-	1/8	12	-	-	1/8	12
Citharichthys arctifrons	2/5	40	-	-	1/8	12	-	-	-	-
Lephophidium cervinum	-	-	-	-	1/8	12	-	-	-	-
Urophycis sp.	-	-	-	-	1/8	12	-	-	1/8	12
Urophycis regius	-	-	-	-	2/8	25	-	-	-	-
flounder - juvenile	2/5	40	1/3	33	2/8	25	2/4	50	3/8	37
fish eggs	-	-	-	-	1/4	25	-	-	-	-
fish larvae	-	-	-	-	2/4	50	-	-	1/4	25
skate egg cases	1/5	20	-	-	-	-	-	-	-	-
unidentified	1/5	20	-	-	-	-	1/4	25	1/4	25
SHELL										
Arctica	3/6	50	1/3	33	5/8	62	2/4	50	2/8	25
Aquipecten irradians	-	-	-	-	1/8	12	-	-	-	-
Cardita borealis	-	-	-	-	1/8	12	-	-	-	-
Crassostrea virginica	1/6	16	1/3	33	1/8	12	-	-	-	-
Ensis directus	1/6	16	1/3	33	-	-	-	-	2/8	25
Placopecten magellanicus	2/6	33	1/3	33	2/8	25	1/4	25	1/8	12
Solariella obscura	-	-	-	-	1/4	25	-	-	-	-
Spisula	2/6	33	1/3	33	2/8	25	1/4	25	1/8	12
cockle	-	-	-	-	-	-	-	-	1/8	12
fossil oyster	-	-	-	-	1/8	12	-	-	1/8	12
unidentified	-	-	-	-	-	-	-	-	-	-
UNKNOWN	1/6	16	1/3	33	1/4	25	1/4	25	1/4	25

Table B-33

Otter Trawl
Species List
Station 2

CRUISE	8-21-69	5-02-70	5-06-70	5-07-70	5-08-70	5-10-70	5-03-71
PORIFERA							
yellow sponge	1/2 trawl	x	x	-	x	1 qt	1 1/4 gal
unidentified #1	-	-	-	9 gal	-	-	-
unidentified #2	-	-	-	1 qt	x	-	-
finger sponge	-	x	-	-	-	-	-
HYDROIDS	-	x	-	-	-	-	-
Obelia sp.	-	-	-	-	3 qt	-	-
Obelia longissima	-	-	-	many	-	-	-
ECTOPROCTS							
Eucratia lorica	-	-	-	1 pt	1/2 pt	-	-
ECHINODERMS							
unidentified starfish	20	x+8	x	-	-	-	-
Asterias forbesi	100	-	7	10	19	4	2
Asterias vulgaris	100	-	-	-	7	-	20
Ophiopholus aculeata	-	-	-	6	6	1	-
Echinarachnius parma	-	x+2	-	-	3	2	2
unidentified urchin	-	-	-	1	-	-	-
BIVALVES							
Arctica islandica	1	-	-	-	-	-	-
Placopectin magellanicus	-	1	-	-	-	-	-
CEPHALAPODS							
unidentified squid	-	-	x	-	-	-	-
GASTROPODS							
Lunatia (*Polinices*)	13	-	-	-	-	-	-
AMPHIPODS							
Aegenina longicornis	-	many	-	many	-	-	-
DECAPODS							
Cancer irroratus	20	10	10	1	6	4	11
FISH							
Hemipterus americanus	1	-	-	1	1	-	-
Lephophidium cervinum	-	-	-	-	1	-	-
Lophius americanus	1	-	-	-	-	1	-

Table B-33 (concluded)

CRUISE	R-01-69	S-02-70	S-06-70	S-07-70	S-09-70	S-10-70	S-03-71
Merluccius bilinearis	14	1	-	1	-	-	1
Myoxocephalus octodecimspinosis	3	1	-	-	-	-	-
Paralichthys dentatus	-	-	-	-	1	-	-
Paralichthys oblongatus	2	-	-	-	-	-	1
Prionotus carolinus	5	1	-	-	-	2	3
Prionotus evolans	-	-	-	-	-	7	-
Pseudoparalichthys americanus	2	-	-	1	1	-	1
Raja eglanteria	-	-	-	-	-	9	-
Raja erinacea	4	-	1	1	-	-	-
Scophthalmus aquosa	3	-	-	-	-	2	-
Urophycis chuss	3	1	3	-	-	-	-
Urophycis regius	-	-	-	1	10	-	1
Stenotomus chrysops	-	-	-	-	-	-	1
angel fish	-	-	2	-	-	-	-
flounder-juvenile	-	-	2	-	-	-	-
ocean pout	2	-	-	-	-	-	-
yellowtail flounder	20	2	-	-	-	2	-
skate egg cases	-	7	-	2	12	-	-
Data from sorted sample	x			x	x	x	x
Data from station log		x	x				
SHELL							
Arctica islandica	-	4	2	1	-	2	-
Crassostrea virginica	-	-	-	1	-	-	-
Placopectin borealis	-	-	-	-	-	1	-
Spisula solidissima	-	5	3	11	5	1	1
fossil oyster	-	2	1	-	-	-	-
Placopectin sp.	-	-	-	-	-	1	-
common stalked anemone	x						
pink egg masses	x						

Table B-34

Otter Trawl
Species List
Station 4

	[illegible]	[illegible]	[illegible]
PORIFERA			
yellow sponge	3/4 trawl	-	-
unidentified #1	-	8	1
unidentified #2	-	-	3/4 pt
HYDROIDS	-	few	-
Obelia longissima	-	-	few
ECHINODERMS			
white urchin	2	-	-
Asterias forbesi	-	-	3
Henricia sanguinolenta	-	-	1
Echinarachnius parma	45	-	-
GASTROPODS			
Lunatia (Polinices)	1	-	-
Polinices egg case	-	-	1
DECAPODS			
Cancer irroratus	34	2	1
Homarus americanus	-	-	1
Pagurus sp.	-	1	-
FISH			
Hemipterus americanus	1	-	-
Lophius americanus	-	1	-
Merluccius bilinearis	16	1	-
Myoxycephalus octodecimspinosis	1	-	-
Paralichthys oblongatus	2	1	-
Prionotus carolinus	6	4	-
Pseudoparalichthys americanus	3	-	-
Raja erinacea	-	1	-
Scophthalmus aquosa	5	-	-
Urophycis chuss	2	2	1
Urophycis regius	-	-	1
ocean pout	1	-	-
fringe flounder	3	-	-

Table B-34 (concluded)

[illegible]	[illegible]	[illegible]	[illegible]
yellowtail flounder	11	-	-
toad fish	1	-	-
skate egg cases	many	2	-
SHELL			
Arctica	10%	-	-
Crassostrea virginica	-	-	1
fossil oyster	1	-	-
Mercenaria	-	1	-
Placopectin	10%	-	-
Spisula solidissima	80%	6	14
Data from sorted sample	x		x
Data from station log		x	

Table B-35

Otter Trawl
Species List
Station 5

CRUISE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PORIFERA							
yellow sponge	3 pieces	much	1/2 samp	-	-	2 1/4 gal	1/2 gal
unidentified #1	-	-	-	1/2 pt	-	-	-
unidentified #2	-	-	-	1 pt	-	1/4 pt	-
HYDROIDS							
Obelia sp.	-	-	-	1 large colony	-	1/2 pt	-
MEDUSAE							
unidentified	-	-	-	-	75	-	-
ECTOPROCTS							
unidentified	-	-	-	1 colony	-	-	-
Eucratia lorica	-	-	-	1/2 pt	-	1/2 pt	-
ECHINODERMS							
unidentified starfish	27	many	1	-	-	-	-
Asterias forbesi	-	-	-	12	1	14	-
Asterias vulgaris	-	-	-	3	-	2	-
Ophiopholis aculeata	-	-	-	12	-	1	-
Echinarachnius parma	-	-	-	-	-	-	6
GASTROPODS							
Polinices egg case	-	-	-	1	-	-	-
CEPHALAPODS							
Ilex illecebrosus	-	-	-	-	-	1	-
DECAPODS							
Cancer irroratus	many	5	1	4	-	16	8
Pagurus annulipes	-	-	-	-	-	4	-
FISH							
Citharichthys arctifrons	-	-	-	2	-	-	-
Hemipterus americanus	1	-	-	-	-	-	-
Lophius americanus	2	-	-	1	-	-	-
Merluccius bilinearis	6	-	1	-	-	-	2

Table B-35 (concluded)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Myoxycephalus octodecimspinosis	15	-	-	-	-	-	-
Paralichthys oblongatus	10	1	-	-	-	1	-
Prionotus carolinus	7	8	-	-	-	14	-
Prionotus evolans	-	-	-	-	-	11	-
Pseudoparalichthys americanus	4	-	-	-	-	-	-
Raja eglanteria	-	-	-	-	-	16	-
Raja erinacea	7	-	-	-	-	-	-
Scophthalmus aquosa	-	-	-	-	-	5	-
Urophycis chuss	7	3	11	7	-	-	-
Urophycis regius	-	-	-	1	-	-	3
flounder-juvenile	-	-	1	-	-	-	-
ocean pout	1	1	-	-	-	-	-
fringe flounder	1	-	-	-	-	-	-
yellow-tail flounder	8	7	-	-	-	4	-
witch flounder	1	-	-	-	-	-	-
skate egg cases	-	-	-	2	-	1	-
fish - unidentified	-	-	1	-	-	-	-
SHELL							
Arctica islandica	90%		1 clapper	5+2 clapper	-	5+6 clapper	1
Crassostrea virginica				5			
Scallops				7			
Spisula solidissima						2	2
clapper			1				
Data from sorted sample	x			x	x	x	x
Data from station log		x	x				

Table 8-36

Otter Trawl
Species List
Station 6

[illegible]	[illegible]	[illegible]	[illegible]
PORIFERA			
yellow sponge	much	-	2 pieces
unidentified #1	-	1 qt	-
HYDROIDS			
Obelia longissima	-	1/4 pt	-
ANTHAZOA			
Stalked anemone	several	-	-
ECTOPROCTS			
Eucratia lorica	-	1 colony	-
ECHINODERMS			
unidentified starfish	many	-	-
Asterias forbesi	-	27	4
Asterias vulgaris	-	-	7
Echinarachnius parma	-	-	6
Ophiopolis aculeata	-	2	-
GASTROPODS			
Lunatia (*Polinices*) heros	-	1	-
Polinices egg case	-	1	-
DECAPODS			
Cancer irroratus	20	7	1
Homarus americanus	-	1	-
Libinia dubia	1	-	-
POLYCHAETES			
Potamilla reniformis	-	6	-
FISH			
Merluccius bilinearis	-	1	-
Myoxycephalus octodecimspinosis	1	1	-
Paralichthys oblongatus	1	-	-

Table B-36 (concluded)

[illegible]	[illegible]	[illegible]	[illegible]
Prionotus carolinus	5	-	-
Pseudoparalichthys americanus	1	-	-
Raja erinacea	3		
Scophthalmus aquosus	-	1	-
Urophycis chuss	12	2	-
yellow-tail flounder	6	-	-
skate egg cases	2	-	-
SHELL			
Arctica islandica	9	-	1
Spisula solidissima	1		1
Data from sorted sample		x	x
Data from station log	x		

Table B-37

Otter Trawl
Species List
Station 8

CRUISE	8-21-69	5-02-70	5-06-70	5-07-70	5-08-70	5-10-70	5-03-71
PORIFERA							
yellow sponge	20% trawl	1 gal	-	-	1 1/2 qt	1 pt	TRAWL EMPTY
unidentified #1	-	-	x	3 gal	-	-	
unidentified #2	-	-	-	1/2 pt	1 piece	1 1/2 pt	
unidentified #3	-	-	-	4 pieces	-	-	
HYDROIDS							
Obelia	-	-	-	-	-	some	
Obelia longissima	-	-	-	1/2 pt	-	-	
SCYPHAZOAN							
unidentified	-	-	-	-	3	-	
Cyanea arctica	-	-	-	3	-	-	
ANTHAZOA							
Pennatula aculeata	-	-	-	-	-	2	
ECTOPROCTS							
unidentified	-	-	-	1 colony	colonies	-	
Eucratia lorica	-	-	-	1/4 pt	-	-	
black-encrusting	-	-	-	-	-	some	
ECHINODERMS							
unidentified starfish	-	-	5	-	-	-	
Asterias forbesi	1000	-	5	16	9	4	
Asterias vulgaris	1000	-	-	3	6	-	
Ophiopholis aculeata	1	-	-	2	-	6	
Echinarachnius parma	100's	x	-	19	49	-	
GASTROPODS							
Lunatia (Polinices) heros	1	-	-	-	-	1	
ISOPODS							
Idotea phosphorea	-	-	-	1	-	-	
DECAPODS							
unidentified crab	-	-	7	-	-	-	
Cancer irroratus	11	4	-	-	1	5	

Table B-37 (concluded)

CRUISE	P-01-69	S-02-70	S-04-70	S-07-70	S-09-70	S-10-70	S-03-71
POLYCHAETES							
unidentified	-	-	-	-	-	x	
FISH							
Merluccius bilinearis	22	-	1	-	-	-	
Paralichthys oblongatus	7	-	-	-	-	1	
Prionotus carolinus	-	-	-	-	-	21	
Prionotus evolans	-	-	-	-	-	9	
Pseudoparalichthys americanus	-	-	-	-	-	1	
Raja erinacea	6	-	-	-	-	1	
Stenotomus chrysops	-	-	-	-	-	7	
Urophycis chuss	13	-	-	-	-	-	
Urophycis regius	-	-	-	3	-	-	TRAWL EMPTY
flounder juvenile	-	-	-	-	1	-	
finfish-juvenile	-	-	-	-	1	-	
yellow-tail flounder	2	1	-	-	-	5	
all mouth flounder	1	-	-	-	-	-	
skate egg cases	-	-	-	-	-	2	
Scophthalmus aquosa	3	-	-	-	-	-	
SHELL							
Arctica islandica	-	1 clap	clap	-	2	2	
Crassostrea virginica	-	-	2	-	-	3	
Ensis directus	-	-	1	-	1	-	
Spisula solidissima	-	-	4	-	20	16	
Placopectin magellanicus	-	-	4	-	-	-	
Data from sorted sample	x			x	x	x	
Data from station log sheets		x	x				x

Table B-38

Otter Trawl
Species Summary List

SPECIES	STATIONS 2		4		5		6		7	
	A	B	A	B	A	B	A	B	A	B
PORIFERA										
yellow sponge	6/7	86	1/3	33	5/7	71	2/3	66	4/6	66
unidentified #1	1/7	14	2/3	66	1/7	14	1/3	33	2/3	33
unidentified #2	2/7	29	1/3	33	2/7	29	-	-	3/3	50
unidentiried #3	-	-	-	-	-	-	-	-	1/6	16
finger sponge	1/7	14	-	-	-	-	-	-	-	-
HYDROIDS										
Obelia	1/7	14	1/3	33	-	-	-	-	-	-
Obelia longissima	1/7	14	1/3	33	-	-	1/3	33	1/6	16
MEDUSAE - unidentified	-	-	-	-	1/7	14	-	-	-	-
SCHYPHAZOANS - unidentified	-	-	-	-	-	-	-	-	1/6	16
Ciannia arctica	-	-	-	-	-	-	-	-	1/6	16
ANTHAZOA										
stalked anemone	1/7	14	-	-	-	-	1/3	33	-	-
Pennatula occulenta	-	-	-	-	-	-	-	-	1/6	16
ECTOPROCTS - unidentified	-	-	-	-	1/7	14	-	-	2/6	33
Eucratia lorica	2/5	40	-	-	2/7	29	1/3	33	1/6	16
black - encrusting	-	-	-	-	-	-	-	-	1/6	16
ECHINODERMS										
unidentified starfish	3/7	43	-	-	3/7	43	1/3	33	1/6	16
Asterias forbesi	5/7	57	1/3	33	3/7	43	2/6	66	4/6	66
Asterias vulgaris	2/7	29	-	-	2/7	29	1/3	33	2/6	33
Henricia sanquinolenta	-	-	1/3	33	-	-	-	-	-	-
Ophiopholis aculeata	3/7	43	-	-	2/7	29	1/3	33	3/6	50
Echinarachnius parma	4/7	57	1/3	33	1/7	14	1/3	33	4/6	66
unidentified urchin	1/7	14	1/3	33	-	-	-	-	-	-
BIVALVES										
Arctica islandica	1/7	14	-	-	-	-	-	-	-	-
Placopecten magellanicus	1/7	14	-	-	-	-	-	-	-	-
Spicula	-	-	-	-	-	-	-	-	-	-

Column A = # times species occurred/# times station sampled

Column B = column A expressed as a percent.

Table B-38 (continued)

SPECIES	STATIONS 2 A	2 B	4 A	4 B	5 A	5 B	6 A	6 B	7 A	7 B
GASTROPODS										
Lunatia (Polinices) heros	1/7	14	1/3	33	-	-	1/3	33	2/6	33
Polinices egg case	-	-	1/3	33	1/7	14	1/3	33	-	-
CEPHALAPODS										
unidentified squid	1/7	14	-	-	-	-	-	-	-	-
Illex illecebrosus	-	-	-	-	1/7	14	-	-	-	-
AMPHIPODS										
Aeginina longicornis	2/7	29	-	-	-	-	-	-	-	-
ISOPODS										
Idotea phosphorea	-	-	-	-	-	-	-	-	1/6	16
DECAPODS										
Cancer irroratus	7/7	100	3/3	100	6/7	86	3/3	100	4/6	66
Homarus americanus	-	-	1/3	33	-	-	1/3	33	-	-
Libinia dubia	-	-	-	-	-	-	1/3	33	-	-
Pagurus sp.	-	-	1/3	33	-	-	-	-	-	-
Pagurus annulipes	-	-	-	-	1/7	14	-	-	-	-
unidentified crab										
POLYCHAETES-unidentified	-	-	-	-	-	-	-	-	1/6	16
Potamilla reniformis	-	-	-	-	-	-	1/3	33	-	-
FISH										
Citharichthys arctifrons	-	-	-	-	1/7	14	-	-	-	-
Hemipterus americanus	3/7	43	1/3	33	1/7	14	-	-	-	-
Lepophidium cervinum	1/7	14	-	-	-	-	-	-	-	-
Lophius americanus	2/7	29	1/3	33	2/7	29	-	-	-	-
Merluccius bilinearis	4/7	57	2/3	66	3/7	43	1/3	33	2/6	33
Myoxocephalus octodecimspinosis	2/7	29	1/3	33	1/7	14	2/3	66	-	-
Paralichthys dentatus	1/7	14	-	-	-	-	-	-	-	-
Paralichthys oblongatus	2/7	29	2/3	66	3/7	43	1/3	33	2/6	33
Prionotus carolinus	4/7	57	2/3	66	3/7	43	1/3	33	1/6	16
Prionotus evolans	1/7	14	-	-	1/7	14	-	-	1/6	16
Pseudopleuronectes americanus	4/7	57	1/3	33	1/7	14	1/3	33	1/6	16
Raja eglanteria	1/7	14	-	-	1/7	14	-	-	-	-
Raja erinacea	3/7	43	1/3	33	1/7	14	1/3	33	2/6	33

Table B-38 (concluded)

SPECIES	STATIONS 2 A	2 B	4 A	4 B	5 A	5 B	6 A	6 B	7 A	7 B
Scophthalmus aquosa	2/7	29	1/3	33	1/7	14	1/3	33	1/6	16
Stenotomus chrysops	1/7	14	-	-	-	-	-	-	1/6	16
Urophycis chuss	3/7	43	3/3	100	4/7	57	2/3	66	1/6	16
Urophycis regius	3/7	43	1/3	33	2/7	29	-	-	1/6	16
angel fish	1/7	14	-	-	-	-	-	-	-	-
flounder-juvenile	1/7	14	-	-	1/7	14	-	-	1/6	16
finfish-juvenile	-	-	-	-	-	-	-	-	1/6	16
toad fish	-	-	1/3	33	-	-	-	-	-	-
ocean pout	1/7	14	1/3	33	2/7	29	-	-	-	-
fringe flounder	-	-	1/3	33	1/7	14	-	-	-	-
yellow-tail flounder	3/7	43	1/3	33	3/7	43	1/3	33	3/6	50
witch flounder	-	-	-	-	1/7	14	-	-	-	-
allmouth flounder	-	-	-	-	-	-	-	-	1/6	16
skate egg cases	3/7	43	2/3	66	2/7	29	1/3	33	1/6	16
unidentified egg masses	1/7	14	-	-	-	-	-	-	-	-
fish - unidentified	-	-	-	-	1/7	14	-	-	-	-
SHELL										
Arctica islandica	4/7	57	1/3	33	5/7	71	2/3	66	4/6	66
Crassostrea virginica	1/7	14	1/3	33	1/7	14	-	-	2/6	33
Ensis directus	-	-	-	-	-	-	-	-	2/6	33
Placopecten borealis	1/7	14	-	-	-	-	-	-	-	-
Placopecten magellanicus	-	-	-	-	-	-	-	-	1/6	16
Scallops	-	-	-	-	1/7	14	-	-	-	-
Spisula solidissima	6/7	86	3/3	100	2/7	29	2/3	66	3/6	50
Placopecten sp.	1/7	14	1/3	33	-	-	-	-	-	-
Mercenaria	-	-	1/3	33	-	-	-	-	-	-
fossil oyster	2/7	29	1/3	33	-	-	-	-	-	-
clapper	-	-	-	-	1/7	14	-	-	-	-

Table B-39

Seasonal Occurrence - Fish
Station 2 - Otter Trawls

	May	June	July	August	September	October	November
Hemipterus americanus	69			70		70	
Lepophidium cervicum						70	
Lophius americanus	69						70
Merluccius bilinearis	69 70	71		70		70	
Myoxycephalus octodecimspinosis	69 70						
Paralichthys dentatus						70	
Paralichthys oblongatus	69	71					
Prionotus carolinus	69 70	71					70
Prionotus evolans						70	
Pseudoparalichthys americanus	69	71		70		70	
Raja eglanteria							70
Raja erinacea	69		70	70			
Scophthalmus aquosa	69						70
Urophycis chuss	69 70		70				
Urophycis regius		71		70		70	
Stenotomus chrysops		71					
angel fish			70				
flounder-juvenile			70				

Table B-39 (concluded)

	May	June	July	August	September	October	November
ocean pout	69						
yellow-tail flounder	69 70						70
skate egg cases	70			70		70	

Table B-40

Seasonal Occurrence - Fish
Station 6 - Otter Trawls

	May	June + July no samples	August
Hemipterus americanus	69		
Lophius americanus	70		
Merluccius bilinearis	69 70		
Myoxycephalus octodecimspinosis	69		
Paralichthys oblongatus	69 70		
Prionotus carolinus	69 70		
Pseudoparalichthys americanus	69		
Raja erinacea	70		
Scopthalmus aquosa	69		
Urophycis chuss	69 70		70
Urophycis regius			70
ocean pout	69		
fringe flounder	69		
yellow-tail flounder	69		
toad fish	69		
skate egg cases	69 70		

Table B-41

Seasonal Occurrence - Fish
Station 5 - Otter Trawls

	May	June	July	August	September	October	November
Citharichthys arctifrons				70			
Hemipterus americanus	69						
Lophius americanus	69			70			
Merluccius bilinearis	69	71	70				
Myoxocephalus octodecimspinosus	69						
Paralichthys oblongatus	69 70						70
Prionotus carolinus	69 70						70
Prionotus evolans							70
Pseudoparalichthys americanus	69						
Raja eglanteria							70
Raja erinacea	69						
Scophthalmus aquosa							70
Urophycis chuss	69 70		70	70			
Urophycis regius		71		70			
Flounder-juvenile			70				
Ocean pout	69 70						
Fringe flounder	69						

Table B-41 (concluded)

	May	June	July	August	September	October	November
yellow-tail flounder	69 70						70
witch flounder	69						
skate egg cases				70			70
fish- unidentified			70				

Table B-42

Seasonal Occurrence - Fish
Station 6 - Otter Trawls

	May	June	July	August
Merluccius bilinearis				70
Myoxycephalus octodecimspinosis	70			70
Paralichthys oblongatus	70			
Prionotus carolinus	70			
Pseudoparalichthys americanus	70			
Raja erinacea	70			
Scophthalmus aquosa				70
Urophycis chuss	70			
yellow-tail flounder	70			
skate egg cases	70			

Table B-43

Seasonal Occurrence - Fish
Station 8 - Otter Trawls

	May	June	July	August	September	October	November
Merluccius bilinearis	69		70				
Paralichthys oblongatus	69						70
Prionotus carolinus							70
Prionotus evolans							70
Pseudoparalichthys americanus							70
Raja erinacea	69						70
Stenotomus chrysops							70
Scophthalmus aquosa	69						
Urophycis chuss	69						
Urophycis regius				70			
flounder-juvenile						70	
finfish-juvenile						70	
yellow-tail flounder	69 70						70
all-mouth flounder	69						
skate egg cases							70

APPENDIX B-3

SEDIMENT DATA

Tables B-44 and B-45

Table B-44

STATISTICAL CALCULATIONS FOR MECHANICAL ANALYSIS OF SEDIMENTS

Graphic Mean (M_z) = $(\phi 16 + \phi 50 + \phi 84)/3$

Inclusive Graphic Standard Deviation (σ_I) =

$$\frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

σ_I under .35φ very well sorted
.35 - .50φ well sorted
.50 - .71φ moderately well sorted
.71 - 1.00φ moderately sorted
1.0 - 2.0φ poorly sorted
2.0 - 4.0φ very poorly sorted
over 4.0φ extremely poorly sorted

Inclusive Graphic Skewness (Asymmetry)

$$(SK_I) = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

SK_I + 1.00 to + .30 strongly fine skewed
+ .30 to + .10 fine skewed
+ .10 to - .10 near-symmetrical 0.00 = symmetrical
- .10 to - .30 coarse-skewed
- .30 to -1.00 strongly coarse-skewed

Graphic Kurtosis (Peakedness) (K_G) = $\dfrac{\phi 95 - \phi 5}{2.44\ (\phi 75 - \phi 25)}$

K_G under 0.67 very platykurtic
0.67 - 0.90 platykurtic
0.90 - 1.11 mesokurtic (normal curve K_G = 1.00)
1.11 - 1.50 leptokurtic
1.50 - 3.00 very leptokurtic
over 3.00 extremely leptokurtic

Table B-45
Grain Size Scales for Sediments
(from R. L. Folk: Petrology of Sedimentary Rocks 39)

Phi (φ)	Wentworth Size Class	Millimeters	
-12.0		4096	
	Boulder		
-8.0		256	
	Cobble		GRAVEL
-6.0		64	
	Pebble		
-2.0		4	
	Granule		
-1.0		2.00	
	Very Coarse Sand		
0		1.00	
	Coarse Sand		
1.0		0.50	
	Medium Sand		
2.0		0.25	SAND
	Fine Sand		
3.0		0.125	
	Very Fine Sand		
4.0		0.0625	
	Coarse Silt		
5.0		0.03125	
	Medium Silt		MUD
6.0		0.0156	